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CO-FIRING OF SOLID WASTES AND COAL AT AMES: PULVERIZED COAL

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16. ABSTRACT

This report presents and evaluation of the Ames Solid Waste Recovery System through the third full year of its operation (1978). This evaluation includes the operating experience and economics of the refuse processing plant, the characterization of the various material flow streams within the refuse processing plant, and the thermodynamic and mechanical performance and the environmental emissions of the 35 MW suspension fired steam generator modified by a dumpgrate installation.

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Hazardous Waste Engineering Research Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs and regulations of the Environmental Protection Agency, the permitting and other responsibilities of State and local governments and the needs of both large and small businesses in handling their wastes responsibly and economically.

This report describes the first continuous full-scale solid waste recovery system for the processing and burning of municipal solid waste as a supplementary fuel for power generation commenced operation in the City of Ames, Iowa. This report provides the cumulative results of the Ames, Iowa, refuse processing plant experience during its third full year of operation (1978). It provides basic data on the economics of operating the plant, the operating experience, the characterization of refuse-derived fuel, and the performance and environmental emissions results from the study of the performance of the suspension-fired steam generator at the City of Ames.

The information contained herein will be of interest to those designers or users who are contemplating or working with a system similar to the Ames system.

For further information, please contact the Alternative Technologies Division, of the Hazardous Waste Engineering Research Laboratory.

David G. Stephan, Director
Hazardous Waste Engineering Research Laboratory

ABSTRACT

The objective of this project is to conduct an in-depth evaluation of the environmental, economic, and technical aspects of the municipal resource and energy recovery system in Ames, Iowa. The system includes recovery of ferrous metals, preparation of the refuse-derived fuel, storage for the refuse-derived fuel, and cofiring the refuse-derived fuel with coal in the electric power plant owned by the City of Ames.

The recovery system research program was designed to cover a 3-year period, and this report covers the 3rd year of research. It includes evaluations of the refuse processing plant operation, economics of the total system and individual subsystems, flow stream characterization, and performance and environmental emissions of the suspension-fired steam generator. Data acquired during the first year's evaluation were previously reported in Environmental Protection Agency Report No. EPA-600/2-77-205, "Evaluation of the Ames Solid Waste Recovery System, Part I - Summary of Environmental Emissions: Equipment, Facilities, and Economic Evaluations.".

This report was submitted in fulfillment of Grant No. R803903-01-0 by the City of Ames under the sponsorship of the U.S. Environmental Protection

Agency. Research studies were conducted by Engineering Research Institute of Iowa State University and Midwest Research Institute in cooperation with the Ames Laboratory, Department of Energy. This report covers the period from February 1978 to February 1979.

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SECTION 1

PROJECT ADMINISTRATION

The involvement of various research organizations and funding agencies in this project resulted in the organizational arrangement shown in Figure 1. Specific tasks were directed and monitored by the principal investigators, who were required to forward results as developed. These data were forwarded to Midwest Research Institute (MRI) to be used in their preparation of monthly and quarterly progress reports. These reports were then forwarded to the Environmental Protection Agency (EPA) through the City of Ames project manager. MRI was also charged with the responsibility of comparing data results with those resulting from EPA-St. Louis-Union Electric Company demonstration facility. Ames Laboratory/Department of Energy (DOE) was responsible for development of any new analytical techniques and the major share of analysis of collected species. Additional analysis of coal, refuse-derived fuel (RDF), and ash was performed by the Raltech and ACU Laboratories.

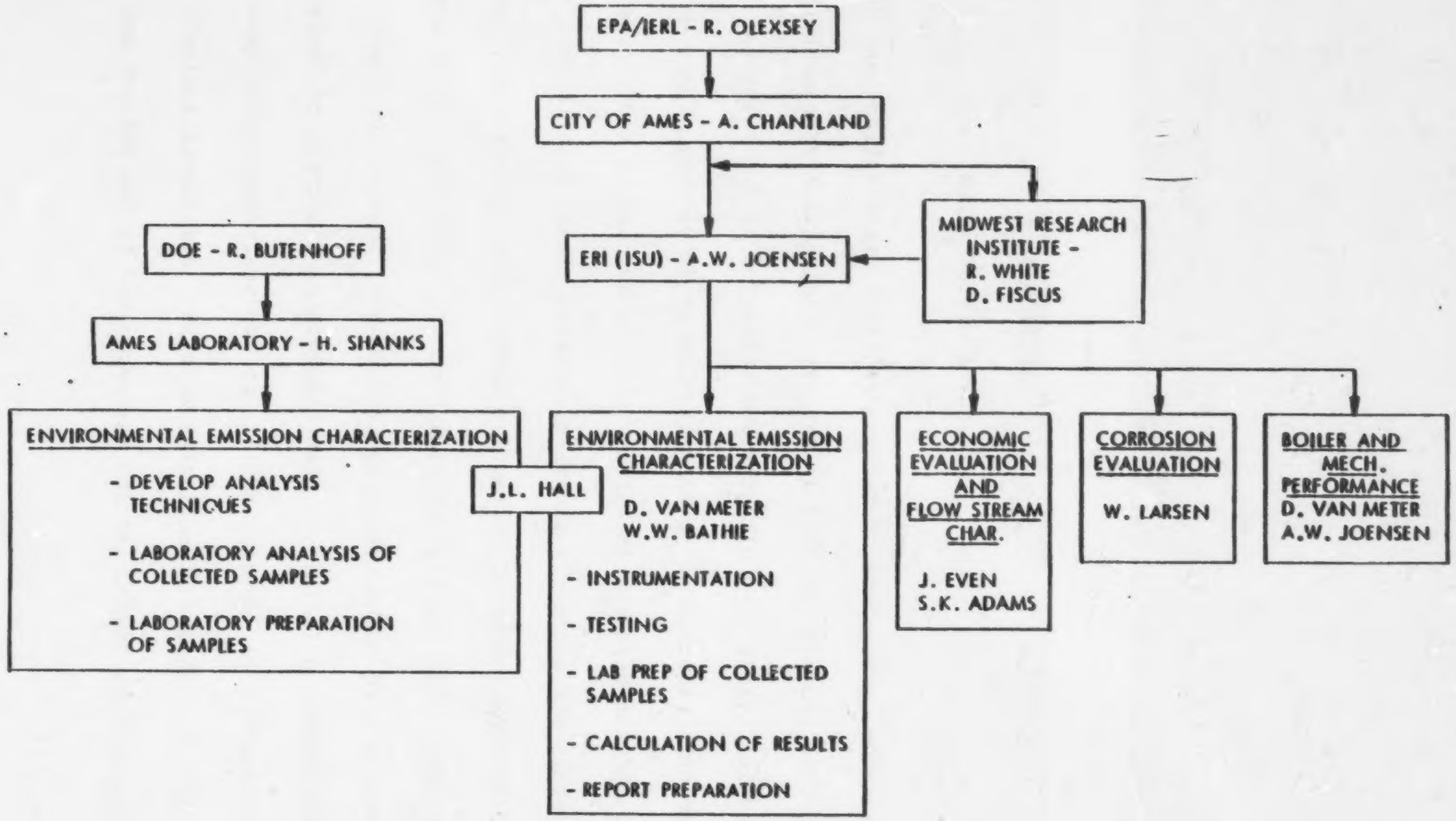
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Figure 1. Organizational diagram.

SECTION 2

INTRODUCTION

The Ames solid waste recovery system is a continuously operating system that is processing municipal solid waste (MSW) to produce a shredded RDF that is burned with Iowa-Western coal mixtures in the tangentially-fired steam generator in Ames municipal power plant. This system consists of a nominal 136 Mg/day (150 ton/day) process plant, a 454 Mg (500 ton) Atlas storage bin, pneumatic transport systems, and the power plant boiler. The process plant incorporates two stages of shredding, ferrous metal recovery, and an air classification (density) separator.

This report presents results and conclusions of the 3rd year effort of a research evaluation of the Ames solid waste recovery system, including the process plant studies, and boiler environmental and thermal performance characterizations. The detailed study objectives are listed in the following section.

This evaluation is a major research program funded by EPA and DOE. Project tasks are being performed jointly by the City of Ames, Iowa, the Engineering Research Institute (ERI) of Iowa State University, the Ames Laboratory/DOE, and MRI.

The EPA funding was used to provide for all manpower, major field equipment purchases, power plant and process plant modifications, laboratory analyses of process plant stream characterization, and other supplies used in the evaluation of both the power plant and process plant. The DOE funding was used to provide laboratory analysis of all field samples procured from the power plant testing.

Additional financial support was provided by ERI, the City of Ames, and the American Public Power Association.

This report presents objectives, system descriptions, test and evaluation procedures, results, and conclusions of the 3rd year research effort.

SECTION 3

EXECUTIVE SUMMARY

The major conclusion from this project is that RDF can be burned successfully when combined with coal in both stoker-fired and suspension-fired boilers to produce electric power. The net cost per megagram to produce RDF was $15.73 in 1976, $12.61 in 1977, and $12.47 in 1978. The yearly reduction in these net costs was due to plant improvements and increased value of the energy contained in RDF.

Major improvements which were made in the Ames solid waste recovery system during the 3-year comprehensive study are as follows:

- Addition of dump grates to the 35 MW suspension-fired steam generator.
- Relocated RDF input nozzles on the 35 MW suspension-fired steam generator to feed RDF below the coal nozzles instead of above the coal nozzles.
- Addition of a grit removal system at the processing plant to improve the quality of the RDF.

- Addition of a dust control system at the processing plant to decrease the failure of electric motors and mechanical equipment, as well as improving the worker environment.
- Addition of two screw conveyors at the Atlas storage bin to allow two pneumatic transport lines to pick up RDF from all four drag conveyors and thus reduce the speed of the pull-ring buckets and the wear on the storage bin floor.
- The mechanical collectors for emission control of the two stoker-fired steam generators were replaced with new ones in 1979 to meet environmental regulations and permit cofiring of RDF and coal in the stoker boilers.

The study of boiler performance showed the necessity to improve the quality of RDF in order to reduce slagging and increase boiler performance. A grit removal system was added in the processing plant which achieved a 24.5% increase in heating value of the RDF from 11,408 to 14,209 kJ/kg, and a 54.5% decrease in ash from 20.99 to 9.55%. Additionally, the boiler fouling impact of RDF has been reduced.

The addition of the dump grate was the most significant change which facilitated the successful cofiring of RDF with coal in the suspension-fired steam generator. The relocation of the RDF injection nozzle to a point below the coal injection was found to be important in its effect on lowering emissions.

Suspension-fired boiler efficiency decreased 3.3 percentage points when operating at 80% steam load with 20% heat input from RDF and decreased 1.33

percentage points at 100% steam load with 20% heat input from RDF. This decrease is attributed to an increase in moisture loss when RDF is fired. Some furnace slagging was encountered during the period prior to installation of the grit removal system, but was reduced after the quality of the RDF was improved by the addition of the grit removal system.

Stack particulate emissions increased slightly with corresponding increases in RDF as a fraction of the fuel input and is due to the presence of lighter RDF particles and increased mass flow. Stack particulate emissions decreased after the RDF injection nozzle was relocated below the coal burners.

Oxides of nitrogen (NO_x) and oxides of sulfur (SO_x) both decrease while chlorides increase with an increase in RDF burning. No discernible trends within the data scatter were noted concerning formaldehyde or hydrocarbon emissions. Increased emissions of the trace elements--zinc, copper, lead, and gallium--corresponded to increases in RDF.

The two stoker-fired boiler units, used as backup to burn RDF, were modified with new mechanical collectors in 1979. These units previously had difficulty meeting particulate emission standards while only firing coal. Subsequent tests conducted on these units by the City of Ames indicated that coal plus RDF can be successfully burned and meet particulate emission standards as a result of this modification along with the grit removal system at the process plant.

Initial results from the study of in situ and inserted samples removed from the 35 MW boiler indicated no boiler tube metal wastage had occurred.

SECTION 4

OBJECTIVES

The major effort of the 3rd year was concentrated on the continued evaluation of the process plant and the tangentially-fired 35 MW steam generator unit No. 7, while Iowa and Western coal mixtures were burned using bottom dump grates with various proportions of RDF.

PROCESS PLANT

The specific objectives for the process plant were to:

- Evaluate the refuse processing plant's monthly production records for trends and to report amounts of refuse processed and material recovered.
- Evaluate the operation of the resource recovery facility in terms of operating experience, labor and maintenance required, energy consumption at the process plant and Atlas storage bin, plant downtime, and equipment malfunctions.
- Evaluate the operating expense and revenues generated from the sale of recovered materials.
- Characterize the process flow stream material at various locations for composition, metal content, heating value, moisture content, and size distribution.

- Characterize environmentally the process building ventilator stack emissions and the ambient dust contained within the process area.
- Provide preliminary characterization of the process plant operation after completion of modifications which included the installation of a disc screen system for fines removal and a plant collection system.

POWER PLANT

Research effort at the power plant was to: evaluate emissions, boiler thermal performance, and potential boiler tube corrosion.

ENVIRONMENTAL EMISSIONS

In the area of environmental emissions, specific objectives were to:

- Characterize the coal and RDF used in the pulverized coal-fired unit No. 7 before and after the dump grate installation.
- Characterize the effluents from the boiler including the flue gas particulates for quantity, size distribution, and composition both before and after the electrostatic precipitator (ESP).
- Determine ESP efficiency by direct measurement of the flow stream concentration and by correlation with fly ash resistivity measurements.
- Analyze the fly ash removed by the ESP and the bottom ash discharged from the boiler and sluiced to the ash pond.
- Analyze flue gases for possible toxic or harmful substances including SO_x, NO_x, chlorides, organic acids, and a selected group of 19 trace elements.

BOILER THERMAL PERFORMANCE

In terms of the thermal performance of the boiler, specific objectives were to:

- Evaluate the boiler efficiency by the indirect method, which accounts for the specific loss associated with the unburned combustibles in the bottom and fly ash, the moisture content, and the dry flue gas loss.
- Analyze other boiler performance parameters such as excess air flow, fuel, and ash characterization, including ultimate analysis, major chemical analysis, ash softening temperatures, and calculation of both slagging and fouling factors.
- Evaluate general operating experience associated with the dump grate installation.

CORROSION

Specific objectives of corrosion-related research were to: evaluate potential boiler furnace waterwall and superheater tube metal wastage by use of in situ welded tube specimens and inserted metal coupon test fixtures.

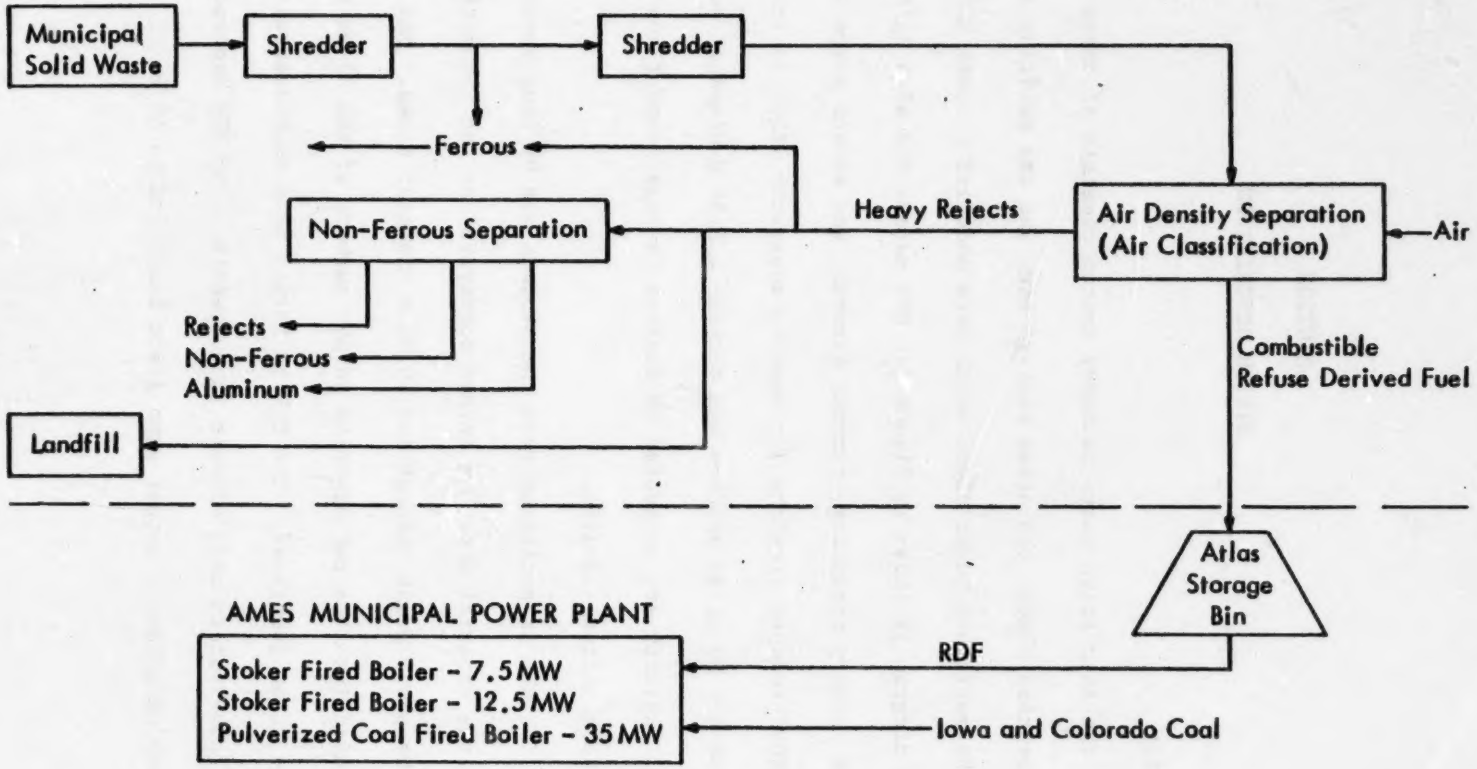
SECTION 5

SYSTEM DESCRIPTION

GENERAL

The Ames solid waste recovery system consists of three major subsystems: the process plant, the Atlas storage bin, and the existing steam generators of the municipal power plant which were modified to burn RDF. A general flow diagram is shown in Figure 2. MSW enters the 45.4 Mg/hr process line where primary shredding, ferrous removal, and second stage shredding occurs. The RDF produced from the air density separator (ADS) is transported 152 m to the 454 Mg Atlas storage bin through a 0.36 m diameter pneumetic transport line. Rejects are subjected to further ferrous removal and are then trucked to the municipal landfill.

The RDF is reclaimed from the storage bin by four bucket sweeps which drop the material into two infeed conveyors for the pneumatic transport 61 m to the power plant through two, 0.20 m diameter pipes. The RDF is currently injected into the two opposite corner burners of the 35 MW tangentially-fired steam generator. The RDF is burned as a supplemental fuel along with the Iowa-Western coal mixture in suspension, and RDF dropout material is burned on a bottom hopper dump grate installed in 1978.



Municipal Solid Waste
Shredder
Shredder
Ferrous
Air Density Separation (Air Classification)
Air
Heavy Rejects
Non-Ferrous Separation
Rejects
Non-Ferrous
Aluminum
Landfill
Combustible Refuse Derived Fuel
Atlas Storage Bin
RDF
AMES MUNICIPAL POWER PLANT
Stoker Fired Boiler - 7.5 MW
Stoker Fired Boiler - 12.5 MW
Pulverized Coal Fired Boiler - 35 MW
Iowa and Colorado Coal

Figure 2. Flow diagram of the Ames solid waste recovery system.

POWER PLANT - UNIT NO. 7

Steam Generator Description

Boiler No. 7 is a Combustion Engineering Company tangentially-fired Type VU-40S steam generator using balanced draft operation with a Ljungstrom regenerative air heater and an ESP, but no economizer. The two-drum unit operates at 5,900 kPa and 485°C steam quality and 163,000 kg/hr of steam flow. An elevation view is shown in Figure 3.

Combustion air is drawn from the upper part of the building, passed through the forced draft fan through the air heater, and enters the furnace through the corner burner assemblies via two main windboxes. Figure 4 is a plan view of the furnace arrangement. Flue gases produced by the fuel combustion in the furnace pass over the primary and secondary superheater tube banks through the convection bank, the air heater, and then through the American-Standard ESP and the induced draft fan (both located outside the building). The flue gases are discharged out the 61 m chimney or stack. Boiler pump discharge feed water is used for superheated steam temperature control, and this spray water is injected between the primary and secondary superheater sections.

High temperature air leaving the air heater is also ducted to the coal pulverizers for use as primary air to transport the pulverized coal to the burner coal nozzles. Tempering air needed to maintain a coal-air temperature of 77°C leaving the pulverizer enters from the basement area through an appropriate damper control. Specific boiler equipment descriptions

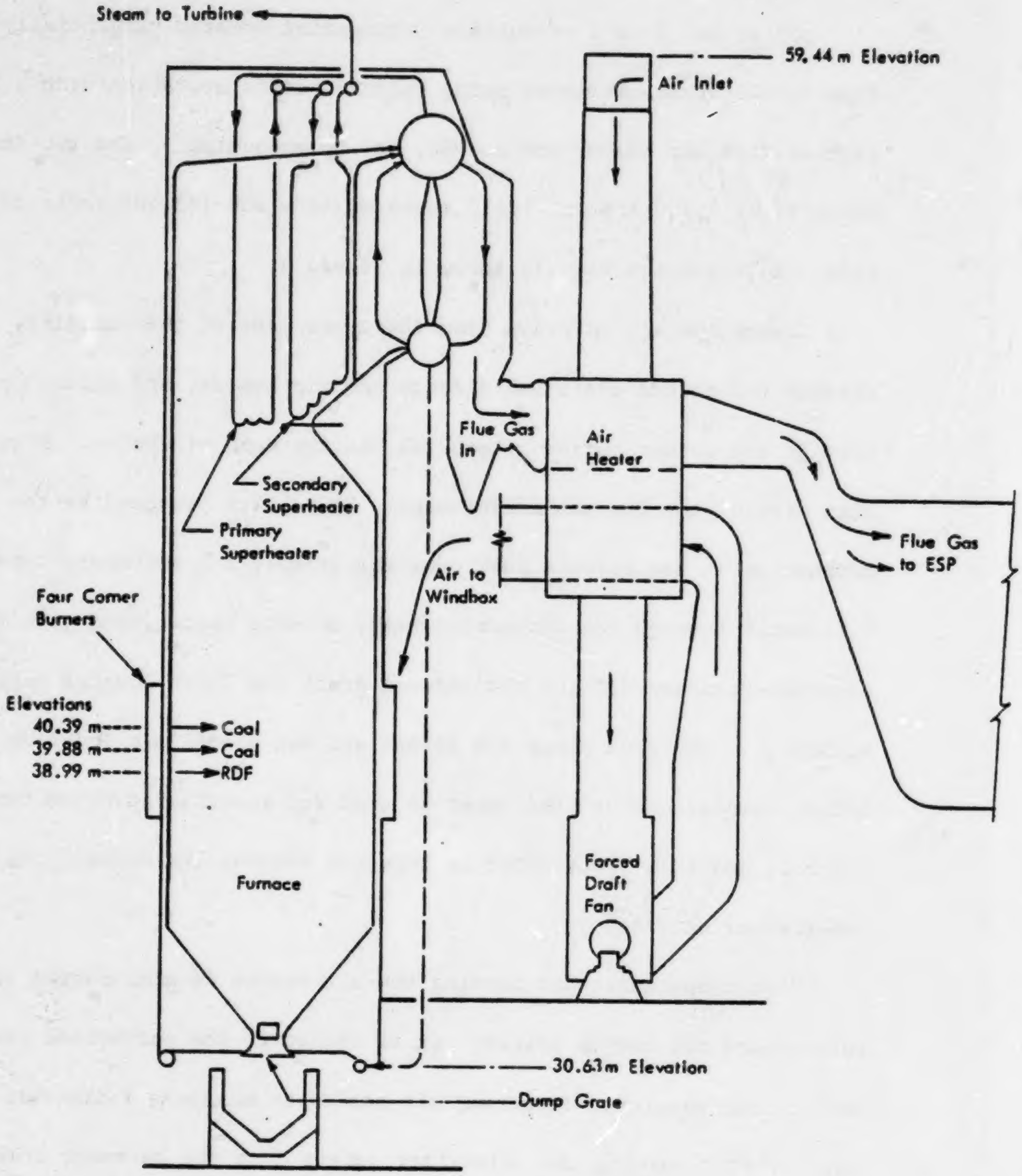

Steam to Turbine
59.44 m Elevation
Air Inlet
Flue Gas In
Air Heater
Secondary Superheater
Primary Superheater
Flue Gas to ESP
Air to Windbox
Four Corner Burners
Elevations
40.39 m
39.88 m
38.99 m
Coal
Coal
RDF
Furnace
Forced Draft Fan
30.63m Elevation
Dump Grate

Figure 3. Boiler unit No. 7 elevator cross-section.

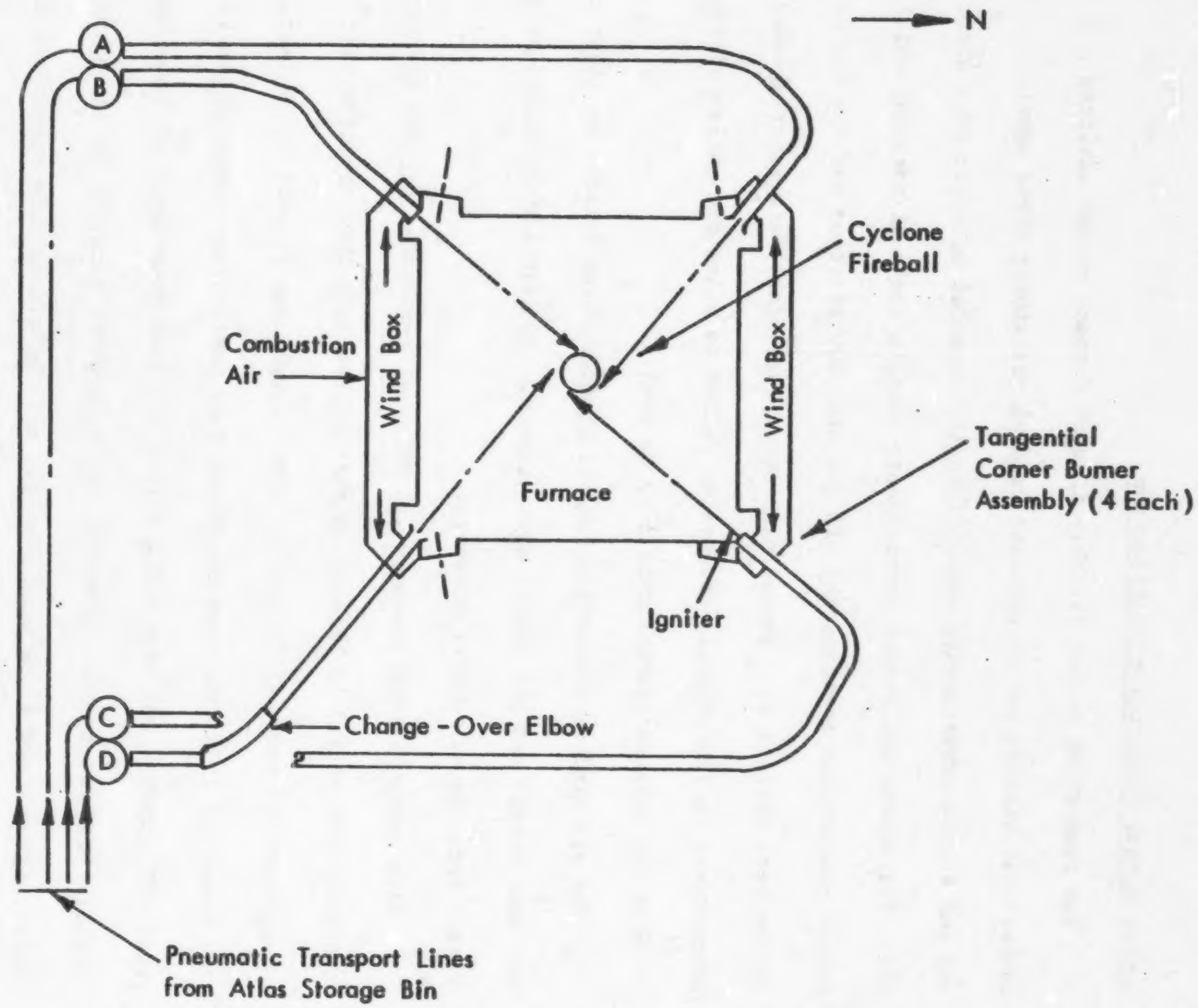

N
A
B
C
D
Cyclone
Fireball
Combustion
Air
Wind Box
Wind Box
Furnace
Tangential
Corner Burner
Assembly (4 Each)
Igniter
Change - Over Elbow
Pneumatic Transport Lines
from Atlas Storage Bin

Figure 4. Unit No. 7 plan view showing tangential firing, corner burners, and RDF pneumatic transport lines.

and design boiler performance are listed in the Appendix.

Corner Burner Compartment Modification

The tangential burner assembly in each furnace corner utilizes a five compartment windbox and an adjacent windbox containing three igniters. The top and bottom compartments were originally intended to admit only auxiliary air. The second and fourth compartments contain the coal nozzles, while the center compartment contains the oil gun used for start-up and the two main gas burners (Figure 5). Heated combustion (secondary) air entering each compartment is individually damper-controlled to allow the boiler operator to move the furnace flame fireball up or down.

The oil windbox contains three oil igniter horns located adjacent to the coal nozzle and gas nozzle compartments. Igniter air is ducted separately from the air heater discharge.

Each corner burner assembly was originally-modified for RDF burning by the insertion of a 3.15 by 4.33 cm rectangular duct into the upper air compartment as shown in Figure 5. After completion of unit No. 7 testing in the summer of 1978, the results showed that particulate emissions increased with RDF burning, but were still within the Iowa Department of Environmental Quality (DEQ) standards. However, the Ames power plant is in the process of constructing a new 65 MW unit (No. 8), and the offset rule specifying total particulate emission from a plant with several stacks is in effect. Compliance with the offset regulation resulted in the relocation in September 1978

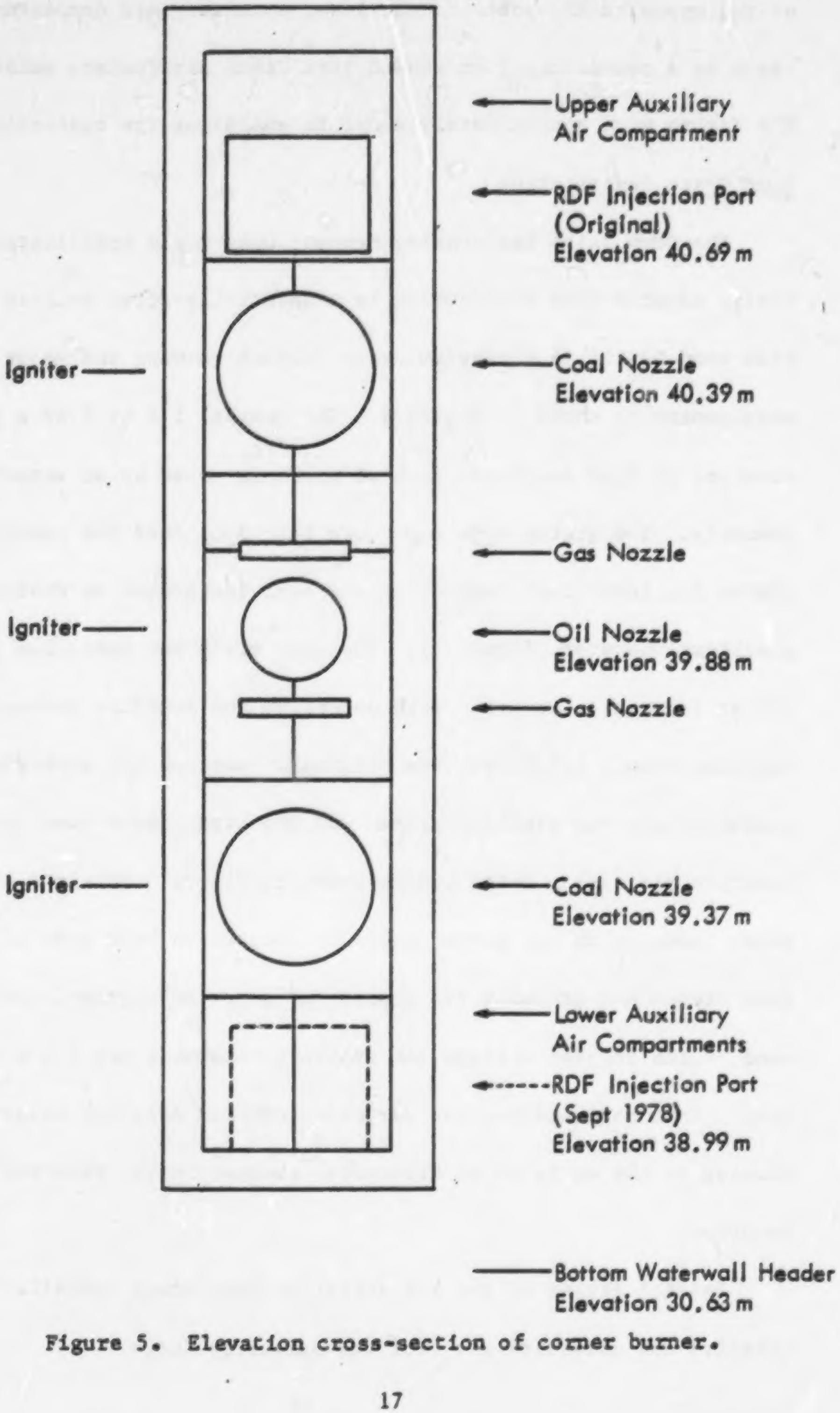

Upper Auxiliary Air Compartment
RDF Injection Port (Original) Elevation 40.69 m
Igniter
Coal Nozzle Elevation 40.39 m
Gas Nozzle
Igniter
Oil Nozzle Elevation 39.88 m
Gas Nozzle
Igniter
Coal Nozzle Elevation 39.37 m
Lower Auxiliary Air Compartments
RDF Injection Port (Sept 1978) Elevation 38.99 m
Bottom Waterwall Header Elevation 30.63 m

Figure 5. Elevation cross-section of corner burner.

of two opposite RDF ports to the lower auxiliary air compartment. Subsequent tests by a consulting firm showed that stack particulate emissions with 20% RDF firing were approximately equal to emissions for coal-only firing.

Dump Grate Installation

The Combustion Engineering Company dump grate modification was a design adapted from application in tangentially-fired boilers burning coal plus wood bark. An elevation cross-section showing the major equipment arrangement is shown in Figure 6. The nominal 1.6 by 5.49 m grate assembly consists of four sections, each of which is moved by an actuating arm and assembly. Two grates form a matched pair such that the pneumatic control allows for individual dumping of one half the grates as desired by the auxiliary operator (Figure 7). The dump grate was installed in the furnace throat (coutant) section. Both underfire and overfire combustion air is supplied from a 1.8 m^3/sec fan originally used on the stoker units. The underfire air and manifold system was the arrangement used previously. The overfire air system installed as shown in Figure 8 consists of a manifold which leads to an air plenum assembly located on both ends of the boiler. Each plenum box contains two square air ports or nozzles, refractory covered, which project through the existing waterwall and 0.3 m observation door. This modification was installed over an existing observation door opening in the wall, so no structural changes in the waterwall tubes were required.

Initial firing of the RDF after the dump grate installation used both overfire and underfire air from the auxiliary fan.

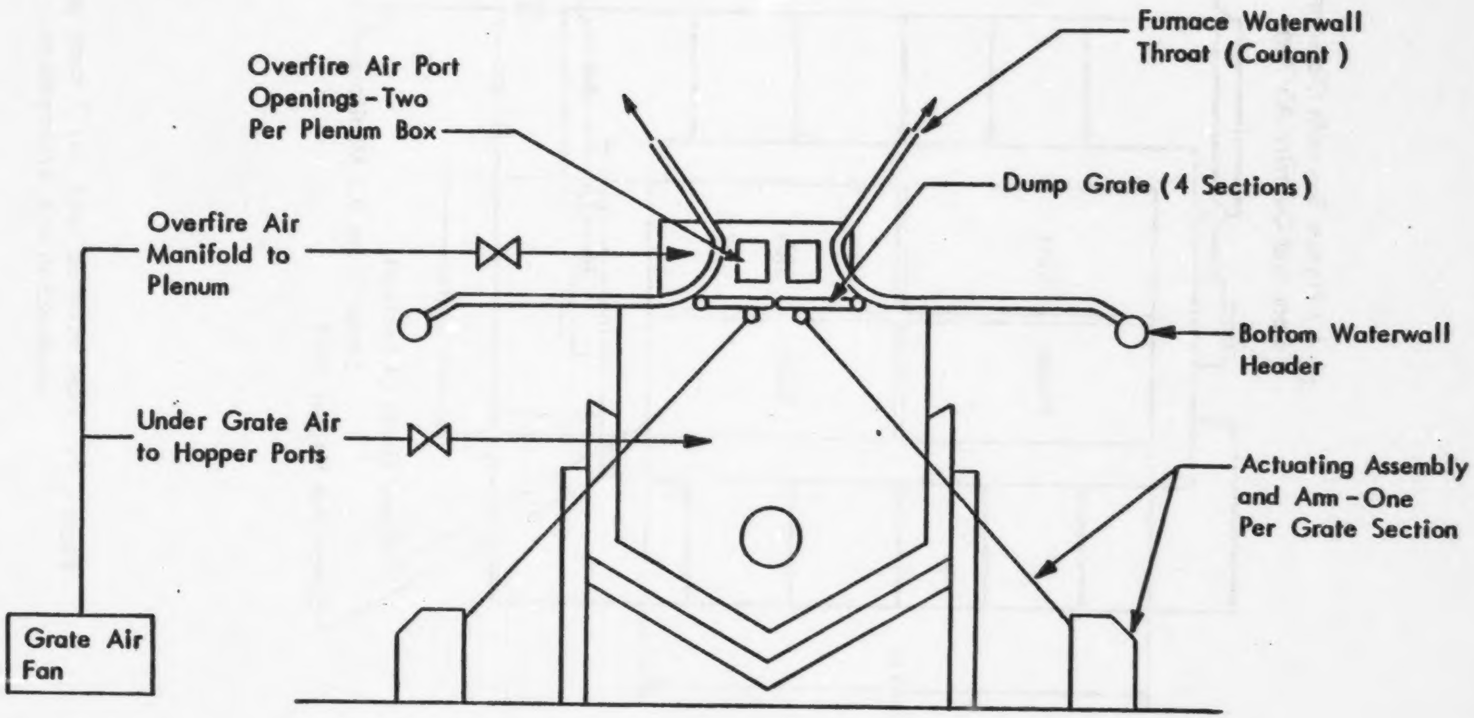

Overfire Air Port Openings - Two Per Plenum Box
Furnace Waterwall Throat (Coutant)
Dump Grate (4 Sections)
Overfire Air Manifold to Plenum
Bottom Waterwall Header
Under Grate Air to Hopper Ports
Actuating Assembly and Arm - One Per Grate Section
Grate Air Fan

Figure 6. Unit No. 7 elevation view of dump grate and actuating assembly.

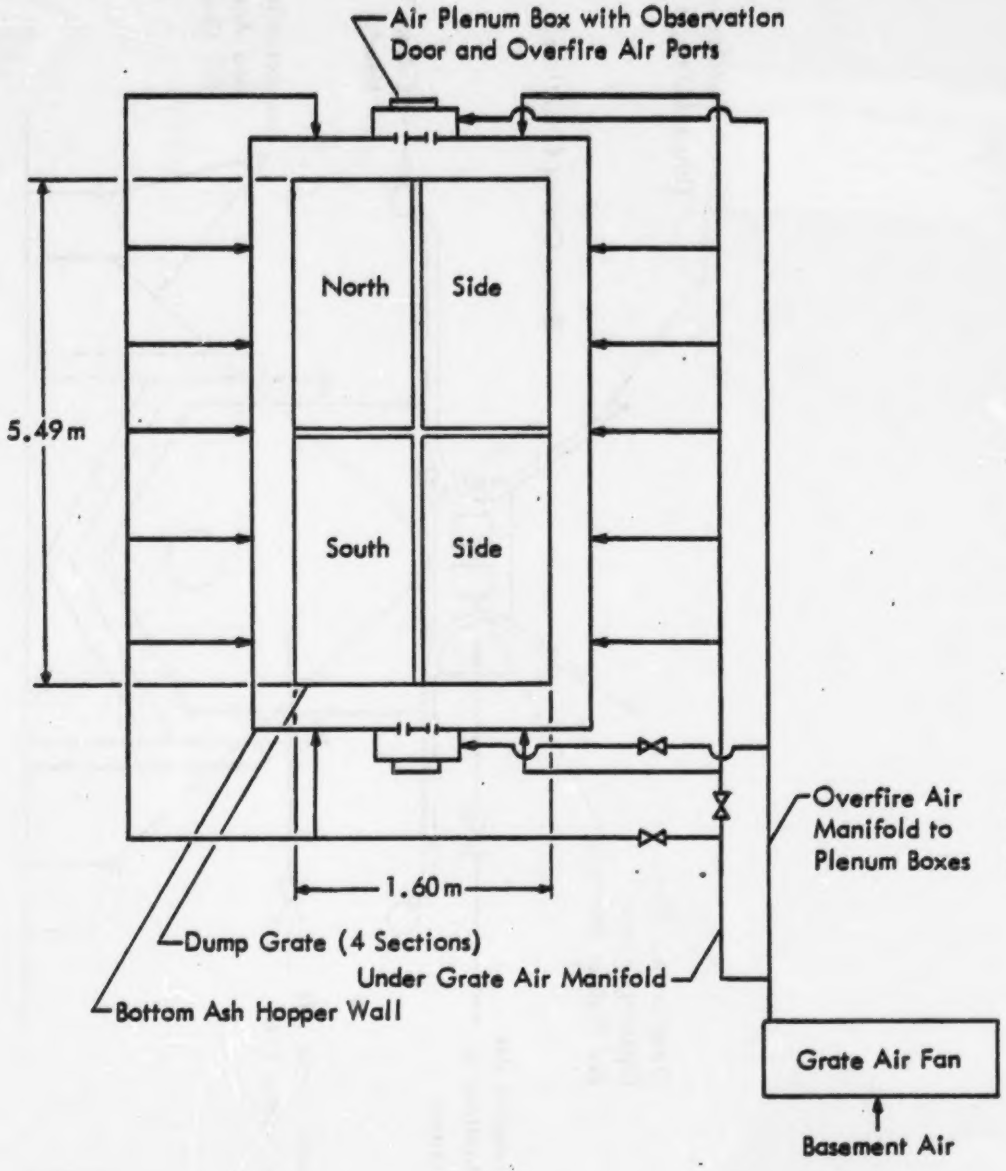

Air Plenum Box with Observation Door and Overfire Air Ports
North
Side
South
Side
5.49 m
1.60 m
Dump Grate (4 Sections)
Under Grate Air Manifold
Bottom Ash Hopper Wall
Overfire Air Manifold to Plenum Boxes
Grate Air Fan
Basement Air

Figure 7. Plan view of unit No. 7 dump grate and combustion air arrangement.

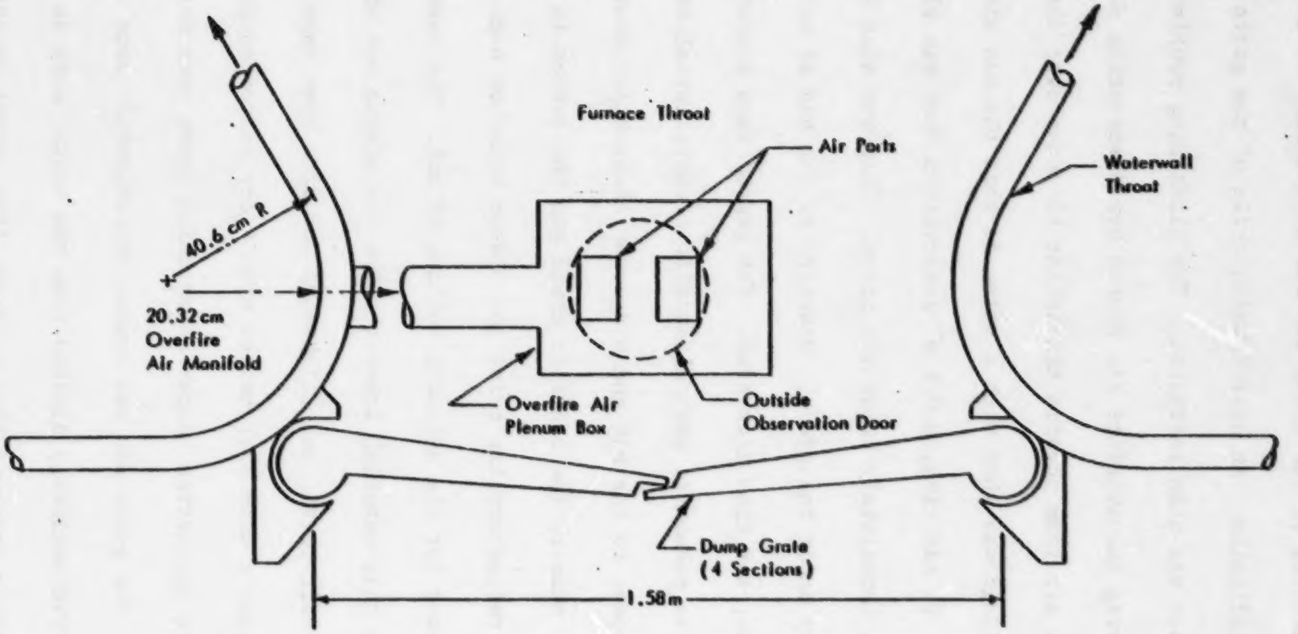

Furnace Throat
Air Ports
Waterwall Throat
40.6 cm R
20.32 cm Overfire Air Manifold
Overfire Air Plenum Box
Outside Observation Door
Dump Grate (4 Sections)
1.58 m

Figure 8. Unit No. 7 elevation view of dump grates and overfire air plenum with air ports and observation door.

Clinkering of the grate ash was experienced if the grate was not dumped periodically. An hour-dumping cycle of the grate ash into the dry bottom hopper was then initiated. The clinkering problem was further reduced by leaving the overfire air plenum box observation doors open to allow basement air from outside the boiler to enter over the grate. The overfire air manifold was shut with a valve so that the fan air entered under the grate.

In addition, a 0.6 m^2 observation door was placed in the north hopper wall immediately below the grate. This was also left open to allow air entry under the grate. However, as the bed of ash on the grate increased in depth, air flow decreased. The grates were dumped by the auxiliary operator at the pneumatic control station console installed also on the north side adjacent to the new and old lower observation doors in the hopper wall. In this manner, the operator could see the grates in the dump cycle. An existing refractory lip below the plenum boxes on each side and above the grate allowed for the periodic buildup of ash. The operator would then manually poke this material loose through the plenum box observation opening in the door-air port. Ash clinkering had also been experienced at the S. D. Warren Company's wood bark boiler with a dry bottom hopper; their solution was to leave two bottom hopper observation doors open for additional air entry.

The grate ash was dumped approximately once an hour, and the material was hydraulically sluiced from the hopper once an 8-hr work shift. If the operator observed that a larger than normal amount of ash had accumulated in the hopper, two sluices per shift were performed.

After the disc screens were installed in the process plant in October 1978 to remove ground glass and other fires, the ash accumulation decreased and the tendency to clinker also was reduced. The grate dump cycle was increased to 1-1/2 hr by some of the auxiliary operators. Occasionally, jamming of the clinker grinder would be caused by fine wire that had not been removed during metal separation at the process plant.

A general description of RDF suspension firing with a dump grate and associated air system is presented in the Combustion Engineering Company pamphlet, "Stoker-Fired Boilers for Cellulose Fuels."[2/]

Dump Grates for the Suspension-Fired Boiler

The conceptual design for the operation of the Ames solid waste recovery system specified burning RDF with coal in the 35 MW (electrical) suspension-type, tangentially-fired unit No. 7. The initial firing rate of RDF was to be 14% (by heat input) and then increased to 20% or 7.3 Mg/hr.

Initial operation in October 1975 resulted in a high dropout of unburned material, including wood and cardboard, into the bottom hopper. The hopper would be completely filled in 1 to 1-1/2 hr, and hopper material removal was extremely difficult using the conventional method of hydraulic sluicing with discharge to an ash pond. Frequent plugging of the ash clinker grinder and the sluice line was experienced.

The power plant then began burning RDF with coal in the 7.5 MW (unit No. 5) or the 12.5 MW (unit No. 6) spreader stoker-fired boilers. These stoker units were also modified to burn RDF and were intended to serve as backup units when the 35 MW unit was down for maintenance. The stoker units were also tested as part of the EPA research evaluation program; these test results were reported previously.[1/]

In early 1976, the power plant personnel attempted to find a solution to burning RDF in unit No. 7. An attempt was made to burn the RDF dropout in the bottom ash hopper. Combustion air was supplied by a 110 m^3/min fan and was introduced into the bottom ash hopper by 14 air ports and an associated manifold system. Each port was 10.2 cm in diameter. The hopper, normally filled with water to quench falling ash, was allowed to fill up with the dropout material. However, burning only occurred on the top of the pile, so this attempt was abandoned.

A final solution to burning RDF in the suspension unit was to install dump grates in the bottom hopper section; this modification was completed on April 26, 1978. Combustion Engineering Company had recommended that a dump grate installation, which is used in the combined firing of shredded bark and coal in paper mills, be used in unit No. 7.

A visit to the S. D. Warren Paper Company in Muskegon, Michigan, was made in December 1976 to inspect the Combustion Engineering dump grate facility, and it was concluded that this operation represented a viable solution. An EPA special grant was obtained which allowed for further boiler modification by the installation of dump grates. After completion of the dump grate installation, RDF was successfully fired in unit No. 7. The results of testing are described later in this report.

Bottom Hopper Ash Sluicing

A bottom hopper composite ash sample for each test was procured by sampling the sluice water discharged at the ash pond by the ash removal system. This sampling procedure was adapted from that used by MRI during their environmental testing performed at the St. Louis-Union Electric RDF demonstration facility.[3/]

At the completion of the boiler test and final dumping of the grate, the bottom ash was hydraulically sluiced to the ash pond as shown in Figure 9. A 2.44 m wide by 7.32 m long wooden sluice box was positioned at the ash pipeline discharge. The sluice water containing the ash spread uniformly over the 2.44 m width so that a sample obtained at each of eight equally-spaced positions was proportional to the flow rate at the same point. Samples were taken in sequence at eight equally-spaced points across the box discharge at 1 min intervals when the boiler was operating at 35 MW, and 30 sec intervals when the boiler was operating at 28 MW during the 25 to 40 min sluice period. A sample of 0.004 m^3 water-ash slurry mixture was obtained by manually drawing a 0.075 m^3 rectangular container through the sluice water at the appropriate time intervals. Each sample was then poured through a fine mesh cloth bag suspended in a 0.21 m^3 drum, thus obtaining as many as 40 to 100 samples which were combined to make one composite sample. At the completion of the sluicing operation, the composite sample was dried and weighed, and the volume of water collected in the drum was measured.

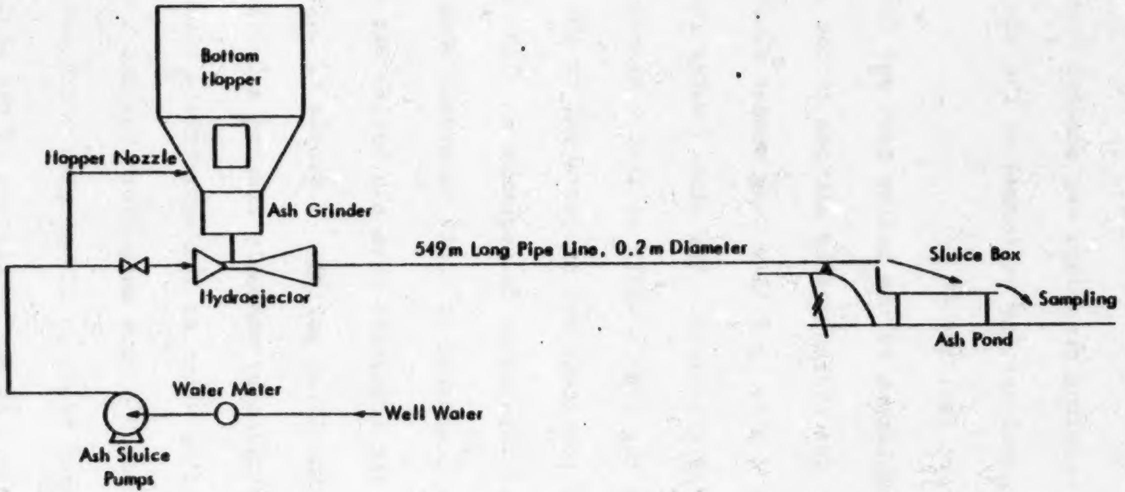

Bottom Hopper
Hopper Nozzle
Ash Grinder
Hydroejector
549m Long Pipe Line, 0.2m Diameter
Sluice Box
Sampling
Ash Pond
Water Meter
Well Water
Ash Sluice Pumps

Figure 9. Flow diagram of bottom ash sluice system.

A water meter at the plant measured the volume of sluice water used. The weight of ash collected per volume of water collected multiplied by the volume of sluice water used permitted calculation of total bottom ash accumulation. Elapsed time measured between grate dump time at pretest and posttest ash removal was used to calculate ash accumulation flow rates into the bottom hopper. On coal-only tests, elapsed firing times were based on the main hopper door closure at pretest and posttest ash removal. The composite ash was then subjected to various laboratory analyses.

PROCESSING PLANT MODIFICATIONS

The Ames solid waste processing facility was shut down for plant modifications which began October 20, 1978, and were completed December 10, 1978. These modifications included installation of a glass/grit removal system, a dust collection system, repairs to the RDF air lock feeder, and change in the flow of the second ADS heavies ferrous removal from the ferrous stream to the reject stream. Money for these modifications was made available by a grant from the United States Congress and administered by EPA through this research project.

Disc Screen System

Installation of a screening system consisting of two Radar disc screens to remove glass/grit/fine material was begun after the plant shut down on October 20, 1978, and was completed December 10 with full-time processing beginning December 11, 1978. The purpose of this equipment is to remove material smaller than 9.5 mm (3/8 in.) that flows from the first to the second stage shredder. In addition, material that is larger than 9.5 mm but smaller than 38 mm (1-1/2 in.) bypasses the second stage shredder, hence reducing the second shredder load. Figure 10 illustrates the system as modified with the two stages of disc screening. The disc screen was installed between the first and second stage shredders with considerable modification to conveyors C-3 and C-11 together with the addition of conveyors C-3A, C-5A, and C-5B.

The first disc screen, known as a scalping screen, is installed at the discharge of conveyor C-2; the Dings ferrous removal system is located, as before, above conveyor C-2. The disc screen consists of 13 multiple rotating shaft assemblies with spaced discs mounted on each shaft. The adjacent shafts are designed to allow interfacing of discs to a designed spacing. Thus, over-sized material is literally bounced along to the discharge end while smaller-sized material passes through the spacing of the intermeshed discs. Nonferrous material falls onto the scalping screen from conveyor C-2 and is transported by the roller screens, allowing material smaller than 38 mm (1-1/2 in.), undersize, to drop through to conveyor C-3A. Material larger than 38 mm flows onto conveyor C-3, which feeds it to the second shredder for further size reduction. Conveyor C-3A carries the undersize to feed the second disc screen.

The second disc screen, containing eight shaft-disc units, has an interface opening that allows material smaller than 9.5 mm (3/8 in.) to drop through to conveyor C-5A; this material comprises the disc screen

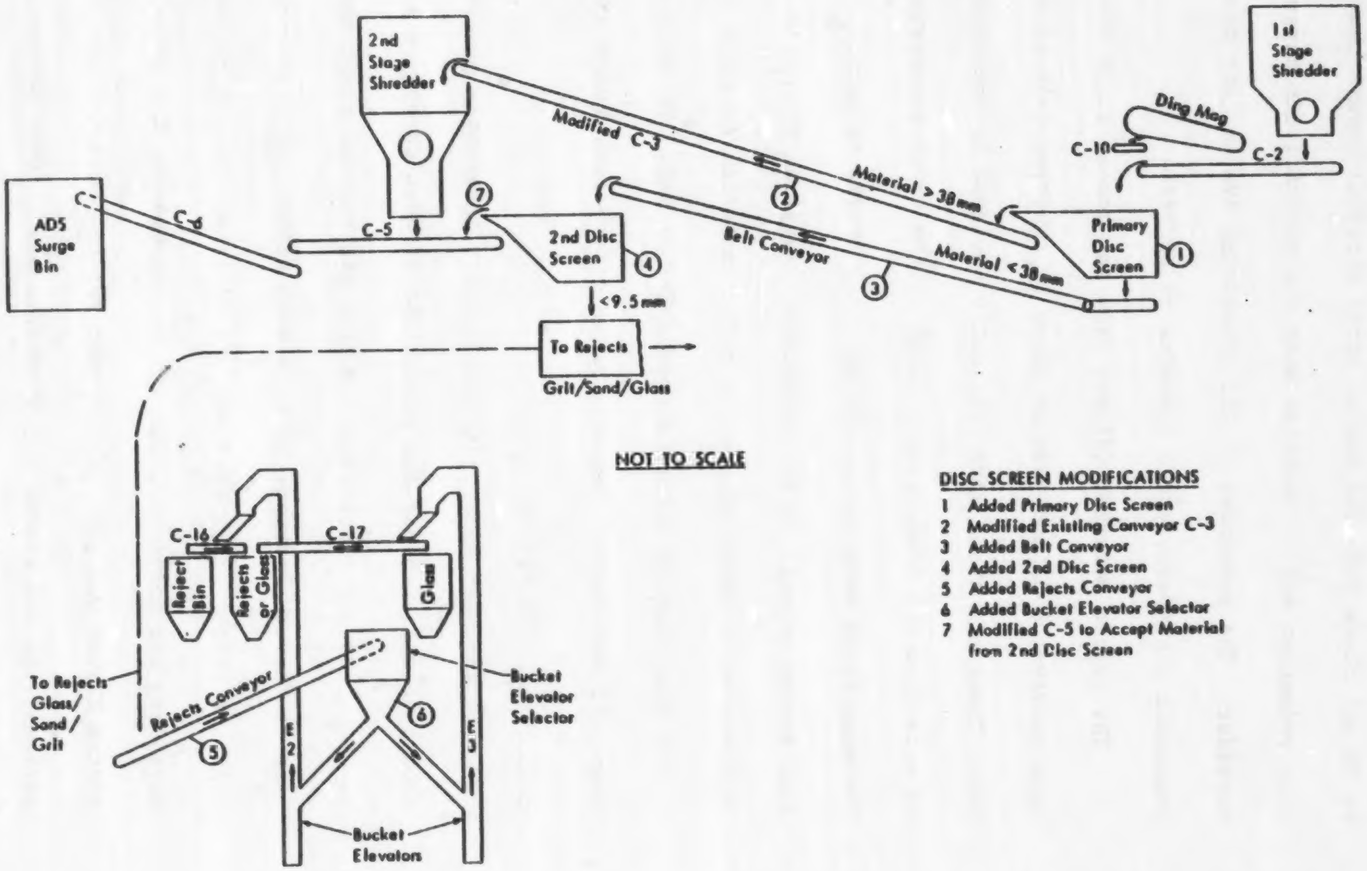

1st Stage Shredder
Ding Mag
C-10
C-2
Primary Disc Screen
①
Material > 38 mm
Material < 38 mm
②
③
Modified C-3
Belt Conveyor
2nd Stage Shredder
⑦
C-5
2nd Disc Screen
④
< 9.5 mm
To Rejects
Grit/Sand/Glass
ADS Surge Bin
C-6
NOT TO SCALE
DISC SCREEN MODIFICATIONS
1 Added Primary Disc Screen
2 Modified Existing Conveyor C-3
3 Added Belt Conveyor
4 Added 2nd Disc Screen
5 Added Rejects Conveyor
6 Added Bucket Elevator Selector
7 Modified C-5 to Accept Material from 2nd Disc Screen
C-16
C-17
Reject Bin
Rejects or Glass
Glass
Bucket Elevator Selector
⑥
E 2
E 3
Rejects Conveyor
⑤
To Rejects Glass/Sand/Grit
Bucket Elevators

Figure 10. Flow diagram showing plant modifications for grit removal system.

system rejects. The material that does not drop through (size ranges 9.5 to 38 mm) flows into the second stage shredder bypass chute without further size reduction and is combined with the material discharged from the second shredder. The remainder of the processing system (air classification, pneumatic transport, etc.) operates as before.

The reject material (fines) from the second stage disc screen falls onto conveyor C-5A and then is moved by conveyor C-5B to elevators E-2 and E-3. These elevators were originally designed to transport the glass and rejects from the nonferrous removal system up to appropriate storage bins. Entrance ports were put in the elevator shafts to permit transport of the disc screen rejects by the elevators. Material from C-5B free-falls onto a diverter valve which allows the reject material to slide through one of two chutes that lead to either elevator E-2 or E-3. To date, elevator E-2 has been used exclusively for moving the disc screen system rejects.

Dust Collection System

The shredder size reduction process inherently generates a large amount of dust. Since the production of dust cannot be eliminated, it must be contained and controlled. During the process plant modifications of October through December 1978, a dust collection system with a Klysler baghouse filter was installed. In addition to dust collection from the shredders and conveyors, the return air leaving the air classification system blower was also routed into the baghouse. Prior to the plant modifications, the ADS system air discharge was a large source of dust.

The baghouse consists of four sections or banks, two of which can be operated at a time to handle the air flow, while the other two are bypassed and shaken down for dust removal. The dust collected by the filter bag units drops into a metering air lock feeder (one for each quadrant) and is drawn into a dust transport fan powered by a 7.4 kW electric motor. This fan discharges into a dust collection cyclone separator. The dust cyclone and its air lock feeder are placed on the surge bin feeding the ADS system, and the air discharged from the cyclone separator is returned to the baghouse system.

The filtered air from the baghouse discharges into the building. Thus, the process plant air is a closed system except for makeup air. This is important in winter months since heat loss would occur if the 1,000 m^3/sec air flow was exhausted outside the building.

Dust collection hoods are located over each of the shredder discharge conveyors, each disc screen, and the discharge region of elevator E-1 onto conveyor C-14.

RDF Air Lock Feeder Repair

The air lock feeder, which is used to inject the flow of RDF from the ADS system to the storage bin, had experienced considerable wear on its inside housing and rotor surfaces. This wear manifested itself in air flowing (leading) back from the transport line to the ADS cyclone separator via the RDF metering screw feeder. The effect of this leakage was to disturb the air vortex in the cyclone and allow material to be carried up into the air discharge flow to the ADS fan, which then resulted in plugging of the reverse air trap used to protect the ADS blower from this material. Also, the loss in pneumatic transport air due to the leak may have contributed to pluggage in the transfer line to the storage bin because of reduced air velocity.

The wear was not concentric around the inside of the air lock housing, so in February 1977, flexible rubber air lock blade tips were installed to provide a better seal and help stop the leakage. This modification, however, required frequent adjustment of the rotor tips to compensate for the wear of the soft material on the blade tip.

During the period of plant modification, the worn surface of the air lock housing was built up and refinished with epoxy material. The coating was applied with a trowel but, unfortunately, was not a precision application. The air lock specifications call for a maximum clearance of 0.127 mm (0.005 in.). When the rotor was installed, it would not rotate because of insufficient clearance, and attempts to force it to run by repeated cycling of the drive motor resulted in overheating and failure of the motor. It was necessary to remove the rotor and chip, grind, and sandblast the high spots to make the air lock operational. Although this repair procedure reduced the leakage flow, leakage was still excessive. Thus, a rebuilt air lock with replaceable housing liners has been ordered to replace the present unit.

The lesson learned from this equipment problem is that a first cost saving (fixed versus removable liners) may result in maintenance difficulties with correspondingly high costs. Downtime is estimated to be 1 week when this replacement is made.

Ferrous Removal from Elevator E-1 Reject Stream

Prior to the October 1978 plant modifications, the ferrous material removed by the head pulley magnet on conveyor C-14 was transported by means of a chute to conveyor C-13 and became part of the process plant's ferrous output stream. This ferrous stream was found to contain a great number of contaminants; a nail or staple would be in a piece of wood, for example, in which the mass of wood carried out was larger than the ferrous material to which it was attached. This system was modified with the addition of belt conveyor C-14A to carry this material out as reject instead of as ferrous product. Ferrous removal at this location is needed because the nonferrous separation system, when used, processes the rejects and requires a ferrous-free input. Conveyor C-14A is adjacent to conveyor C-15; both of these conveyors feed conveyor C-16, which in turn transports material into the reject bins.

Total Processing Plant Downtime Since Equipment Modifications, December 1978 through April 1979

The process plant was put in full-scale operation Monday, December 11, 1978, following completion of modifications with only minor difficulties. Plant shutdown occurred Friday, January 19, 1979, due to maintenance required by the Atlas storage bin. The second shutdown occurred Thursday and Friday, March 1 and 2, as a result of a bin fire which had started at noon the preceding day. This shutdown was necessary to empty the bin of smouldering material.

The third shutdown occurred Thursday and Friday, March 22 and 23, due to the inspection of unit No. 7 at the power plant and the resulting lack of RDF usage; hence, the bin became filled. The plant processed the following Monday, March 26, but because of difficulty in retrieving the "old" RDF, it was necessary to stop processing until Wednesday, April 4. The bin material had compacted and congealed, and manual digging was necessary to loosen the material. The bin again required service Tuesday, April 17, resulting in no processing for the day.

Incoming refuse was diverted to the landfill a total of 12 days during the 5 month period, which resulted in an estimated loss of 1,700 Mg with its corresponding loss in fuel credit and ferrous revenues. During the 5 month time period, 13,000 Mg of raw refuse was processed.

SECTION 6

SYSTEM EVALUATION METHODS AND PROCEDURES

PROCESS PLANT PARTICULATE EMISSIONS AND DUST EVALUATION

Emissions from Roof Ventilators

Particulate emissions from the roof ventilators of the refuse plant were evaluated by EPA Method 5 particulate sampling techniques.[4-6] Extensions were added to each of the roof ventilators on the refuse plant to facilitate the sampling. Sampling in the roof ventilator ducts used 24 sampling locations on each of two perpendicular traverses across the diameter of the duct for a total of 48 sample points. At each sample point, the sampling train was operated for 3 min, meaning that a total sample was collected over 144 min of operation. The amount of particulate collected was then determined on both a volume and a time basis. The results are reported in Section 13 of this report.

In addition to sampling emissions from the roof ventilators, high volume ambient air samplers were placed in the plant to determine the dust concentration at specific locations.

Ambient Air Sampling

The ambient air in the refuse processing plant was sampled at three general elevations in the plant by means of high volume samplers modified to contain 10 cm (4 in.) diameter quartz fiber filters on which the particulate matter collected as the sample train operated. Each sample train was operated for 15 min. The weight of sample was then determined for the time span of the test and recorded for each location in the plant.

The three levels sampled in the plant included the floor level in the general vicinity of the first and second stage shredders and below the ADS. The mid-level location sampling was adjacent to the ADS and underneath the bucket elevator in the processing plant. Upper level samples were taken at a walkway in the plant and at the top of the bucket elevator.

Following the weighing of the samples, several representative filters were analyzed to ascertain the typical elements present in the dust and the amounts. The amount of dust in the ambient air of the processing plant and the results of the trace element analysis are presented in Section 13 of this report.

POWER PLANT

Experimental Design

In this study, it was determined that two major factors could be controlled at various levels. These factors were the steam generator load, based either on steam flow generated or megawatts of power generated, and the amount of RDF, based on heat energy input to the boiler. The levels chosen were 60, 80, or 100% nominal steam generator load, and 0, 10, or 20% RDF. To obtain sufficient data for statistical analysis, a factorial experimental design with three replications was devised for the steam generators, as summarized in Table 1. The statistical design was a 3 by 3 by 3 (three loads, three values of RDF, and three replications) full factorial experiment with 27 runs. To ascertain compliance with Iowa Department of Environmental Quality (DEQ) rules, additional miscellaneous testing was done. During these tests, the location of the RDF injection point was changed. The results of all tests of this steam generator are contained in Section 12 of this report.

TABLE 1. TEST MATRIX FOR UNIT NO. 7 EXPERIMENTAL RUNS

Percent load	Percent RDF		
	0%	10%	20%
60%	3 runs (1976)	-	-
80%	3 runs (1976)	2 test runs (1977)	-
100%	3 runs (1976)	-	-
80% (Wyoming coal)	3 runs (1978)	3 runs (1978)	3 runs (1978)
100% (Wyoming coal)	3 runs (1978)	3 runs (1978)	3 runs (1978)
100% (Wyoming coal)	-	-	Compliance tests[a/] 4 runs (1978)

[a/] RDF injection nozzles relocated to below the coal injection nozzle.

To satisfy the objectives of the environmental emissions study, all appropriate input and output streams associated with the operation of the steam generator unit were sampled. A block diagram showing the sample locations of entering and leaving streams is included as Figure 11. The tests on unit No. 7 are summarized in Table 1. All inputs to and outputs from the steam generator were evaluated, including fuel, combustion air, bottom ash, steam, fly ash, and stack gas. All the sampling was conducted on a regular basis except the organic species, which were sampled on intermittent days as manpower, instrumentation, and equipment would allow.

Sampling Methods

Sampling of effluents was conducted according to EPA-prescribed techniques.[4-6] Stack particulate samples were obtained at numerous points in the smoke stack cross-section (see Figure 12). In addition, three stack sampling trains operated simultaneously while another particulate sampling train was located before the particulate collector. Figures 13 and 14 show the sampling location and sampling points at the collector inlet. Input fuel and grate ash were sampled at regular 30-min intervals throughout the test period and then mixed to yield a composite sample. Hopper (fly) ash was sampled at the completion of each experimental run. Combustion air to the boiler was monitored by wet and dry bulb thermometry. Steam flow rate, temperature, and pressure were also recorded at regular intervals.

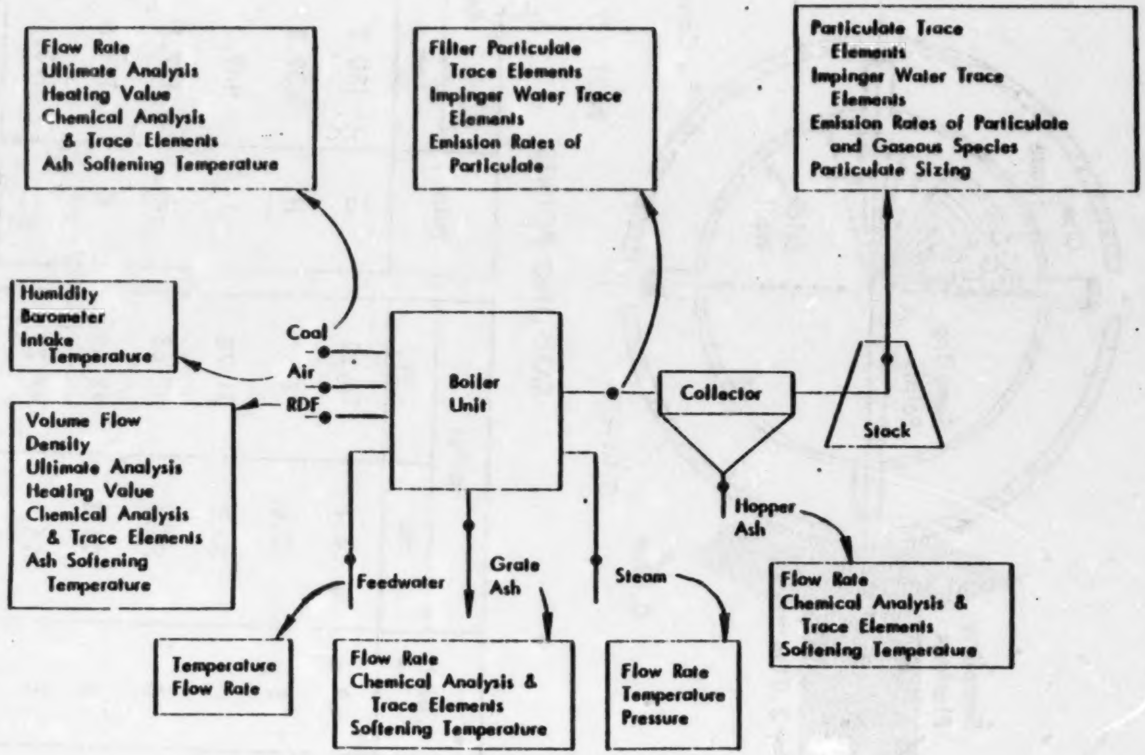
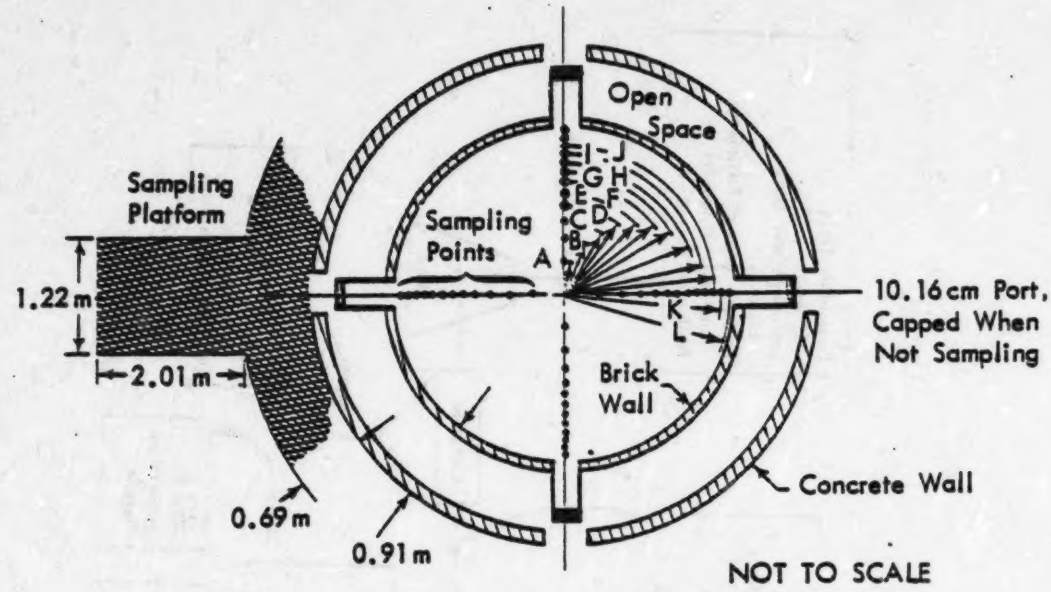

Flow Rate
Ultimate Analysis
Heating Value
Chemical Analysis & Trace Elements
Ash Softening Temperature
Filter Particulate Trace Elements
Impinger Water Trace Elements
Emission Rates of Particulate
Particulate Trace Elements
Impinger Water Trace Elements
Emission Rates of Particulate and Gaseous Species
Particulate Sizing
Humidity
Barometer
Intake Temperature
Coal
Air
RDF
Boiler Unit
Collector
Stack
Volume Flow
Density
Ultimate Analysis
Heating Value
Chemical Analysis & Trace Elements
Ash Softening Temperature
Hopper Ash
Feedwater
Grate Ash
Steam
Flow Rate
Chemical Analysis & Trace Elements
Softening Temperature
Temperature
Flow Rate
Flow Rate
Chemical Analysis & Trace Elements
Softening Temperature
Flow Rate
Temperature
Pressure

Figure 11. Sampling locations.


Open Space
I J
G H
E F
C D
B
A
Sampling Platform
Sampling Points
1.22 m
2.01 m
10.16 cm Port, Capped When Not Sampling
K
L
Brick Wall
Concrete Wall
0.69 m
0.91 m
NOT TO SCALE

SAMPLING POINTS

Point	Radius		Point	Radius	
	cm	in		cm	in
A	36.1	14.22	G	130.3	51.32
B	62.6	24.67	H	139.8	55.05
C	80.7	31.78	I	149.0	58.67
D	95.6	37.63	J	157.5	62.02
E	108.3	42.65	K	165.6	65.22
F	120.0	47.25	L	173.1	68.15

Figure 12. Stack particulate sampling locations.

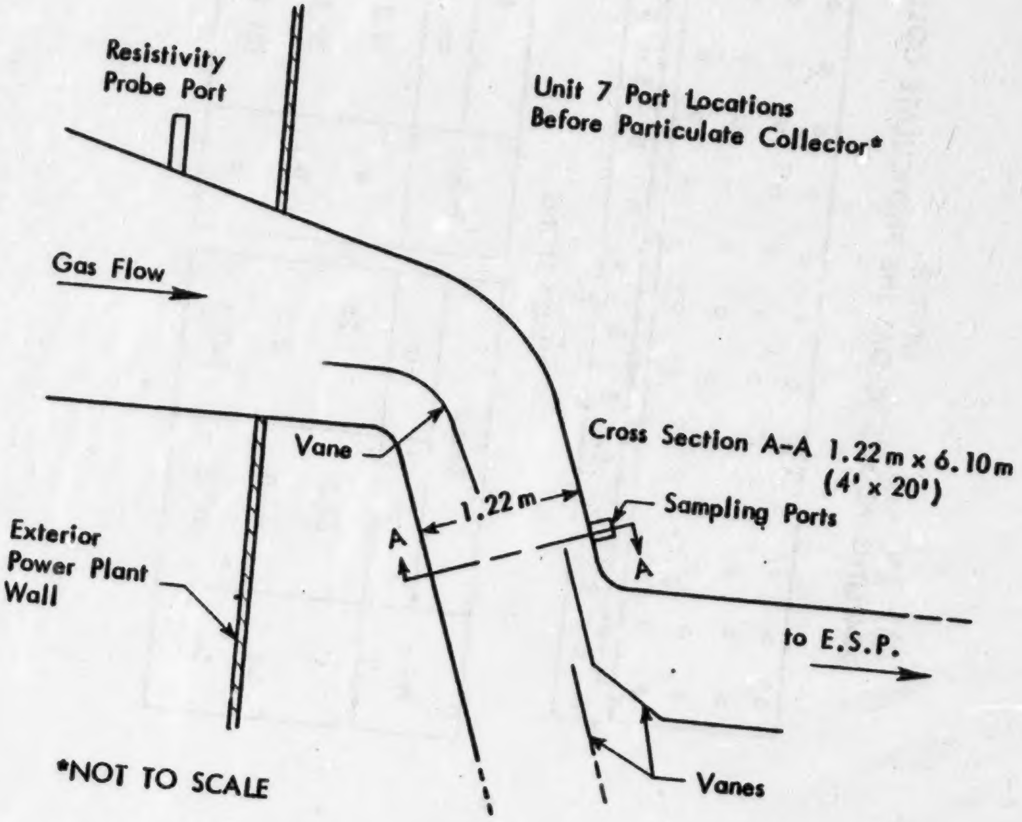
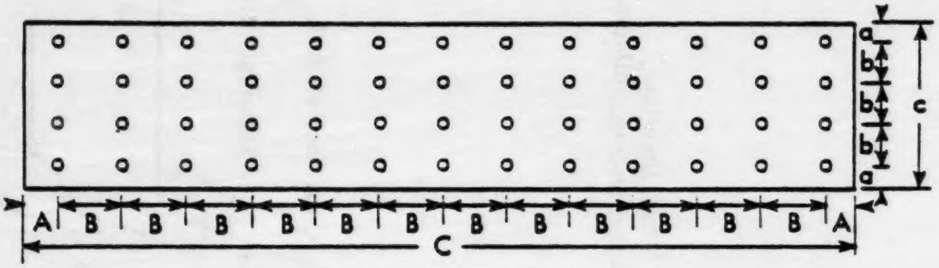

Resistivity Probe Port
Unit 7 Port Locations Before Particulate Collector*
Gas Flow
Vane
Cross Section A-A 1.22 m x 6.10 m (4' x 20')
1.22 m
Sampling Ports
A
A
Exterior Power Plant Wall
to E.S.P.
Vanes
*NOT TO SCALE

Figure 13. Sampling locations at ESP inlet.

UNIT 7
SAMPLING POINTS BEFORE THE PARTICULATE COLLECTOR


a
b
b
b
a
c
A
B
B
B
B
B
B
B
B
B
B
B
B
A
C

DIMENSIONS

Point	Radius	
	cm	in
A	23.5	9.25
B	47.0	18.5
C	609.6	240.0

Point	Radius	
	cm	in
a	15.2	6.0
b	30.5	12.0
c	121.9	48.0

Figure 14. Sampling locations at ESP inlet.

The composite coal and RDF samples were analyzed by the Ames Laboratory. Ultimate analyses and heating values were obtained by standard ASTM methods. Trace elements in the fuels and ash were determined by x-ray fluorescence[4] (XRF) techniques. Trace elements in the sample train impinger solutions were determined by inductively-coupled plasma[5] (ICP) techniques.

The size distribution of the particulates after the dust collector was determined by an Andersen cascade impactor. Particulate samples obtained with the EPA Method 5 sampling train were analyzed by XRF. The impinger solutions from the Method 5 train were analyzed by ICP.

The gases CO_2, CO, O_2, and N_2 in the stack were determined by Orsat techniques. EPA Method 7 was used for evaluation of NO_x levels, and EPA Method 6 was used for measurement of C_1 through C_5 hydrocarbons by gas chromatography (GC). Several modifications[6,7] of the EPA Method 5 train were used to collect samples for analysis of aldehydes and ketones, chlorides, and trace elements.

Organic compounds were sampled by drawing stack gas through a column of macro-reticular resin and also by extraction from particulates collected in the stack. GC and mass spectroscopy (MS) were used for identification and quantification.

Table 2 summarizes the sampling methods used for tests in this study, and Table 3 summarizes the sampling train chemicals and flow rates.

TABLE 2. SUMMARY OF SAMPLING AND ANALYTICAL PROCEDURES

Item sampled	Sampling technique	Analytical procedure
Fuel into boiler	Hourly samples combined	• Trace elements via XRF • Ash via ASTM method • Moisture via ASTM method • HHV via ASTM method
Combustion • Air	Thermometry	• Wet bulb and dry bulb temperature
Ash • Grate (bottom ash)	Grab samples combined to form single composite sample	• Trace elements via XRF or appropriate ASTM method • Ash via ASTM method • Moisture via ASTM method
• Collected fly ash (hopper ash)		• Trace elements in grab sample composite taken from particulate collector hopper ash
Steam		• Flow rate • Temperature • Pressure
Fly ash • Before particulate collector	EPA Method 5 Brinks impactor	• Trace elements in material on filter via XRF
• Stack	Andersen impactor Brinks impactor	• Size distribution via impactor • Trace elements in impinger solutions via ICP
Flue gas • Stack	Orsat	• CO_2, CO, O_2, N_2
	EPA Method 7	• NO_x
	EPA Method 6	• SO_2
	Modified EPA Method 5	• Aldehydes and ketones via method of Carotti and Kaiser • Organic acid via ion chromatograph • Cyanide via ion selective electrode • Phosphorus via spectrophotometer
	Modified EPA methods 5 and 6	• Chlorides via colorimetric and spectrophotometric analysis of part of impinger solutions from SO_x train
	Modified EPA Method 5	• Mercury, arsenic, antimony, and beryllium via ICP
	Grab sample	• C_1 and C_5 hydrocarbons via gas chromatography
	Aspiration across column of macroreticular resin	• Organics (PCB, POM, etc.) via gas chromatograph-mass spectrograph

TABLE 3. SUMMARY OF SAMPLING TRAIN CHEMICALS AND SAMPLING FLOW RATES

Sample train	Impinger number and solution or material 1	2	3	4	5	Flow rate liter/min	Typical sampling time, (min)
Particulate (EPA Method 5)	200 ml distilled H_2O	200 ml distilled H_2O	empty or dry	200 g Drierite	-	Isokinetic	144
Oxides of sulfur (EPA Method 6 modified and with five impingers)	100 ml 80% Isoproponal	100 ml 3% H_2O_2	100 ml 3% H_2O_2	100 ml NaOH	200 g Drierite	8	30
Organic acid (EPA Method 5 modified with Tenax plug)[a]	100 ml NaOH	100 ml NaOH	100 ml NaOH	200 g Drierite	-	8	60
Aldehyde and ketone (EPA Method 5 modified)	empty or dry	100 ml $NaHSO_4$	100 ml $NaHSO_4$	200 g Drierite	-	1	60
Trace element (EPA Method 5 modified with midget impingers)	25 ml NaOH	25 ml ICL	25 ml ICL	10 g Drierite	-	1	60

[a] Tenax plug used to absorb organic vapors from sampled flue gas.

The input fuel and boiler load were held as constant as possible at their preselected nominal values during a given test run. If no difficulties were encountered, each test lasted typically 4 to 5 hr. On some occasions, tests lasted longer because of difficulties that arose concerning sampling, boiler operations, or refuse fed to the boiler. Also, back-to-back tests were accomplished for compliance testing as required and monitored by the Iowa DEQ. Input coal and RDF were sampled at regular 1/2 hr intervals throughout the testing period on any given day. These samples were then mixed to yield an appropriate composite sample.

The stack effluents were generally sampled according to EPA-prescribed techniques.[4-6] The preparation of each sample train included: (a) cleaning the sample train glassware with an appropriate acid wash followed by several distilled water rinses; (b) preparation of chemicals and loading of sample train impingers with appropriate absorbing solutions; (c) weighing and labeling each impinger of each sample train; (d) weighing and loading particulate train filters; (e) checking sample boxes, control boxes, and sample probes for proper operation; and (f) transporting the sampling equipment to the test site and preparing for the test.

Before operation of any sampling train, leak checks were performed from the sampling train probe tip to ensure that each sample train was leak free. No sampling train was operated until it had passed an appropriate leak check. The maximum allowable leak rate was 0.06 liter/min (0.02 cfm) at a sampling train vacuum of 50.1 kPa of mercury (15 in.). This leak rate was also allowed at a lower vacuum if the vacuum level of the leak check was not exceeded during operation of the sampling train. All sample train leak checks during this study complied with this leak rate criterion. A leak check was also performed after each experimental run to ensure that no leaks had developed during the sampling period.

The samples were obtained either isokinetically or proportionally as required, after appropriate calibrations of the sample train dry gas meter, flow orifice, Pitot tube, sampling nozzle, and temperature indicators.

After sampling, the sample train impingers and filters were weighed and prepared for laboratory analysis. The impinger chemicals were transferred to clean reagent bottles, the filters were dried before weighing, and the coal, RDF, and ash samples were appropriately mixed and processed. All samples were then transferred to the Ames Laboratory--DOE.

SECTION 7

REFUSE PROCESSING PLANT EQUIPMENT AND FACILITY EVALUATIONS

GENERAL

This section reviews refuse processing equipment and plant operations for the year 1978 from a technical point of view, not an economic one. The section is divided into seven parts as follows:

- Processing plant activities - A summary of operating experience for the process plant, RDF storage bin, RDF retrieval system, and all major plant subsystems.
- Raw refuse received and materials produced - Monthly summaries of refuse received in terms of type and source together with summaries of principal materials produced from refuse, including RDF, ferrous metal rejects, wood chips, and baled paper.
- Processing plant labor - Annual and monthly summary of labor needed to operate the processing plant described in terms of subsystems and specific labor activities.
- Electrical energy utilization - Analysis of electrical energy required for processing, storage, and retrieval. Energy for processing is also discussed in terms of requirements for operating the various subsystems within the processing plant.

- Processing and downtime - A description of system and subsystem processing performance and downtime, including factors which affected performance or caused downtime.
- RDF conveying system and storage bin - Summary of pneumatic conveying of RDF to the Atlas storage bin and subsequent retrieval and pneumatic conveying to the electric power plant together with a summary and discussion of downtime in the storage and retrieval system and its effect upon the overall solid waste system operations.
- Other plant evaluations - Discussion of other aspects of system performance, including shredder maintenance, mass balance in estimating RDF flow rates, water consumption, net electrical power generation, and coal replaced by using RDF in the electric power plant.

Figure 15 shows an overall conceptual diagram of the refuse processing plant as it existed from January through October 1978. The sequence of the various subsystems can be seen along with the entering, transfer, and exiting flow streams and the conveyor designations. Extensive modifications were made from October through November 1978 which resulted in a new system that is significantly different from the one shown. The modifications, including the addition of a disc screen and dust collection system, and their effects upon basic system design will be discussed in a later section.

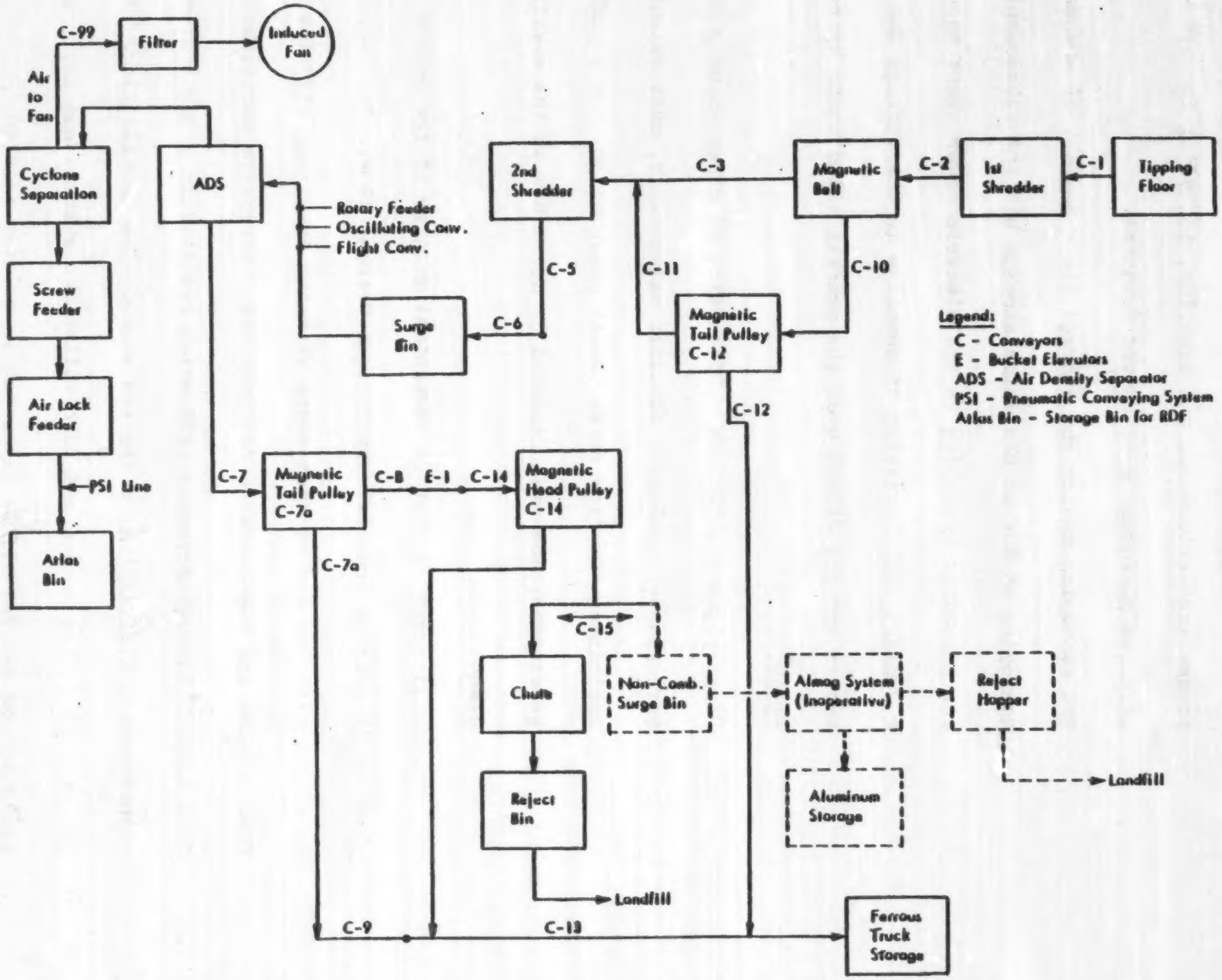

C-99
Filter
Induced Fan
Air to Fan
Cyclone Separation
ADS
Screw Feeder
Air Lock Feeder
PSI Line
Atlas Bin
Rotary Feeder
Oscillating Conv.
Flight Conv.
Surge Bin
C-6
C-5
2nd Shredder
C-3
Magnetic Belt
C-2
1st Shredder
C-1
Tipping Floor
C-11
C-10
Magnetic Tail Pulley C-12
C-12
Legend:
C - Conveyors
E - Bucket Elevators
ADS - Air Density Separator
PSI - Pneumatic Conveying System
Atlas Bin - Storage Bin for RDF
C-7
Magnetic Tail Pulley C-7a
C-8
E-1
C-14
Magnetic Head Pulley C-14
C-7a
C-15
Chute
Non-Comb. Surge Bin
Almag System (Inoperative)
Reject Hopper
Landfill
Aluminum Storage
Reject Bin
Landfill
C-9
C-13
Ferrous Truck Storage

Figure 15. Flow diagram of Ames solid waste processing plant.

In the original system as shown in Figure 15, raw refuse starts through the plant process in the infeed conveyor C-1, proceeding into the first stage or primary shredder. It then travels via conveyor C-3 to the second stage or secondary shredder. Immediately before dropping onto C-3, the ferrous metal is removed by a magnetic belt and transferred directly via C-10 and C-12 to C-13. There is a magnetic pulley on C-12. Following second stage shredding, conveyor C-6 transports material to the ADS system. At this point, light material is lifted by a strong upward air flow and transported via the pneumatic conveying system (PSI) to the Atlas storage bin where it will later be retrieved and transferred by a second PSI to the electric power plant. The heavy material drops out of the ADS onto conveyor belts which, together with elevator E-1, carry material to the trommel screen nonferrous metal separation system and reject bin.

The nonferrous metal system was not in use during 1978. Instead, all heavy material went to the reject bin for subsequent transport by truck to the landfill, with the exception of small amounts of ferrous metal extracted by magnets located on conveyors C-7A and C-14.

Originally, the nonferrous metal separation system was designed to remove aluminum by a high frequency alternating magnetic eddy current. This portion of the overall process was intended to segregate glass, aluminum, other nonferrous metal, and oversized material, the latter to be rerouted through the system.

PROCESSING PLANT ACTIVITIES

This section describes major events occurring in the process plant, RDF storage bin, and RDF retrieval system. In general, the process plant performed reliably through 1978. The only extended shutdown period was from mid-October to mid-December when the disc screen and dust collection systems were being installed. This modification was extensive and required substantial changes in conveyor routing and pneumatics. The result was essentially an updated type of process plant. During the shutdown period, all refuse was diverted to the landfill.

Most other downtime periods of 8 hr or more were caused by problems in the RDF storage bin or in the electric power plant. Table 4 lists the RDF storage bin downtime pattern.

TABLE 4. RDF STORAGE BIN DOWNTIME

Date - 1978	Bin problem	Period of shutdown (hr)
January 4	Electrical problem - motor	8
January 31	Bucket train connection	5
February 6	Sweep drives	8
February 9	Sweep drives	8
March 3	Refuse setting up	8
March 6	Refuse setting up	8
March 16	Bin too full	8
April 3-6	Cleaning out bin	24
May 15-19	Sweep drives	40
May 30-31	Sweep drives	16
June 1	Sweep drives	8
June 14	Sweep repair	3
Total		144

As mentioned, the major downtime for the process plant was from October through December 20 during installation of the disc screen and dust collection systems, at which time all refuse was hauled to the landfill, thus causing a substantial loss in revenue. In addition to the hauling expense, there were the extra costs associated with operating the landfill for burial of refuse which would have otherwise been processed by the plant. The number of days of downtime during this period were as follows:

Month 1978	Days downtime
October	9
November	21
December	10
Total	40

The necessity of hauling refuse to the landfill at other times depended upon the length of downtime and the capacity of the plant to receive incoming refuse on the tipping floor. Downtime for the other 9 months of the year is presented in Table 5.

TABLE 5. PROCESSING PLANT DOWNTIME FOR THE FIRST 9 MONTHS OF 1978

Month	Days downtime
January	1
February	2
March	3
April	4
May	7
June	1
July	0
August	0
September	0
Total	18

The solid waste recovery plant does not eliminate the necessity for a municipal landfill. A landfill is needed for reject material, material that cannot be processed such as demolition matter, and also for disposal of refuse when the process plant is not operating. Table 6 lists the weight of rejects and refuse deposited into the landfill during 1978.

The first 9 months represent operating conditions. During this period, 3,266 Mg of rejects were deposited, an average of 272 Mg/month. In this same period, 2,993 Mg of refuse were taken to the landfill. The amounts of refuse hauled during April and May were large because of the storage bin downtime at the solid waste plant.

TABLE 6. LANDFILL OPERATIONS FOR 1978

Month	Solid waste rejects Megagram (Mg)	Refuse Megagram (Mg)
January	226	0
February	217	0
March	287	103
April	406	517
May	332	1,119
June	595	227
July	396	320
August	464	318
September	343	389
October	275	1,689a/
November	31	2,664a/
December	322	1,361a/
Total	3,89	8,707

a/ Disc screen installation mid-October through mid-December.

During the last 3 months of the year, the solid waste plant was being modified and an unusually large amount of downtime was experienced. As a result, much refuse that would have been processed during those months was diverted to the landfill. Only 4,261 Mg of refuse were processed during the last 3 months as compared with 5,714 Mg taken to the landfill. During November, no refuse was processed. The 12 month totals of reject material and of refuse hauled to the landfill were 3,894 and 8,707 Mg, respectively.

Conversion to tons (or megagrams) from cubic yards is based on average values of 300 lb/yard^3 for refuse and 700 lb/yard^3 for rejects. Trucks carrying rejects are weighed at the process plant. During installation of the disc screen and dust collection systems, refuse hauled to the landfill was monitored by recording refuse truck numbers, trips, and volumetric capacities and then using the 300 lb/yard^3 conversion factor to determine the total mass.

RAW REFUSE RECEIVED AND MATERIALS PRODUCED

An average of 2,852 Mg of refuse was processed each month during 1978, resulting in the production of 2,403 Mg of RDF, 268 Mg of reject material, and 180 Mg of ferrous metal. The aluminum separator and other nonferrous metal systems did not operate during 1978. Wood chips and baled paper were only a small part of the overall recovery system. They do not involve the main sequence of process plant equipment but are separate, peripheral operations. The economic significance of the major products of the system and the impact of the disc screen and dust collection systems upon their production are discussed in another section.

It should be emphasized that the first 9 months of 1978 are the only ones which are representative of a regular production schedule. Since the plant did not operate from October 17 to December 20, these 3 months are not statistically comparable for averaging or for showing trends. Excepting these last 3 months, the quantity of refuse processed varied from 2,594 Mg in February to 3,791 Mg in June. The summer months represented the heaviest usage in spite of the fact that most of the student population, which accounts for approximately half of the city's residents, was absent. The fact that reject material was high suggests the effects of local construction.

RDF is clearly the major product of the system. Reject material and ferrous metals are next in importance, but ferrous metals are more important economically. It is possible that, in the future, additional materials such as heavy combustibles (wood, etc.), aluminum, and other nonferrous metals may be recovered from reject material.

PROCESSING PLANT LABOR

Labor hours allocated to all major process plant subsystems are shown in Table 7. Data are summarized on a 9 month basis, because the plant was shut down for modifications from mid-October through mid-December. Thus, the actual number of labor hours worked during the final 3 months is reduced in each case, but the relative percentages are consistent with previous 9 month data. For this reason, the 9 and 12 month percentages of labor hours allocated to the various subsystems are similar, and it can be seen that the plant operated in a generally consistent fashion throughout 1978.

The major subsystems listed in Table 7 are composed of the following:

Tipping Floor

End loader

Hand sorting nonprocessible materials

Floor sweeper (powered)

Car line (fee collection and traffic control)

TABLE 7. LABOR HOURS BY SUBSYSTEM, 1978

Month	Tipping floor	Shredder system	ADS system	Ferrous system	Almag non-Fe system	Rejected system	Pneumatic (PSI) system
January	559.75	112.50	82.50	107.00	18.50	135.00	7.00
February	447.50	205.75	18.75	79.00	119.50	82.50	10.50
March	530.00	162.00	98.75	282.75	72.50	133.00	19.00
April	508.00	167.75	90.50	167.75	32.50	213.50	5.50
May	375.50	211.00	59.75	131.50	28.50	191.50	26.25
June	437.75	110.25	122.75	150.50	23.00	273.75	21.50
July	480.00	110.75	127.50	108.00	20.50	319.00	80.50
August	548.00	341.50	32.25	99.25	24.00	293.00	66.75
September	542.50	207.50	87.00	98.50	-	225.00	27.00
Subtotal, 9 months	4,429.00	1,629.00	719.75	1,224.25	339.00	1,866.25	264.00
October	316.50	202.25	255.00	93.50	-	185.50	53.75
November	80.50	188.80	404.50	40.70	16.00	136.00	68.50
December	336.00	109.50	66.00	66.00	-	166.50	19.00
Total, 12 months	5,162.00	2,129.55	1,445.25	1,424.45	355.00	2,354.25	405.25
9 month %	42.30	15.56	6.87	11.69	3.24	17.82	2.52
12 month %	38.88	16.04	10.89	10.73	2.67	17.73	3.05
9 month avg	492.11	181.00	79.97	136.03	37.67	207.36	29.33
12 month avg	430.16	177.42	120.44	118.70	29.58	196.19	33.77

Scales (for weighing commercial vehicles)

Emptying baled newspaper bin

Handling tires

Shredder System

Conveyors C-1, C-2, C-3, C-4, C-5, C-6, C-11

Primary shredder

Secondary shredder

ADS System

Flight conveyor

Link belt

Air lock feeder

Cyclone

Rotary screw feeder

C-99

ADS

Ferrous Metals System

Dings magnet

Chute

Trailer for hauling metal (changing trailers)

Conveyors C-7A, C-10, C-12, C-13

Nonferrous Metals System

Aluminum-magnetic separator

Conveyors C-19 to C-27, C-29

Surge bin

Elevator

Trommel screen

Aluminum and nonferrous storage bins

Rejects System

Conveyors C-7, C-8, C-14 to C-17, C-28

Elevators E-1, E-2, E-3, E-4

Pneumatics, PSI

Air lock feeder

PSI line (14 in.) to storage bin

PSI blower

The tipping floor required the largest number of labor hours, accounting for about 40% of the total. (Hours associated with the paper baler and log chipper were excluded since these operations are independent of the main process.) Tipping floor labor consisted primarily of operating the end loader and serving the car line. The latter could be largely eliminated through the use of an automatic coin-activated gate.

The shredder system labor was largely associated with the primary and secondary shredders and infeed conveyor C-1. The shredders required labor during hammer changes or rotations, which occur on the average at 9,072 Mg (10,000 ton) intervals. Infeed conveyor C-1 often required backing up and unplugging.

The ADS system required operating and maintenance labor for many of its components. Performance of the ADS itself was influenced by moisture content, density, and other properties of refuse. The flight conveyor also required labor for repairs and to free material jammed in the bottom chamber which houses the drive sprocket mechanism. In addition, the rotary air lock feeder, twin screw conveyor, cyclone, and link belt all required significant amounts of labor on an irregular basis.

Labor in the ferrous system consisted primarily of trailer change operations. Also, conveyor C-13 required frequent service to clear clusters of steel cans from its exit into the trailer. The Dings magnetic belt and conveyors C-10 and C-12 occasionally had problems with steel cans becoming caught in the magnetic pulley or between the pulley and the conveyor belt, requiring time to clear the material.

The nonferrous metals system did not operate on a production basis during 1978. Labor hours associated with it were allocated almost entirely to installation and to adjustment of new high frequency alternating field magnets.

The rejects system consists entirely of material handling equipment, including four elevators and seven conveyors. Most of these became plugged or jammed occasionally because of excessive material, usually when wet refuse was being processed. E-1 required more service than the other operations for several reasons:

1. It handles all reject material.
2. It is an enclosed system requiring scooping and lifting of material and keeping pace with a variable feed rate.

3. It rises vertically through three levels, which presents more difficult access.

4. The inertia of heavy chains and flight bars together with sprocket drives makes servicing difficult.

The PSI from the process plant to the storage bin includes the rotary air lock feeder, the PSI blower, and approximately 61 m of 35.6 cm (14 in.) diameter underground steel pipe with access at a location near its midpoint. The items requiring the most labor were the pipeline and the air lock feeder. The line is subject to the abrasive action of sand and glass, and holes and worn surfaces cause plugging. The air lock feeder is also subject to abrasion, which increases the clearance between the blades and the inner wall surface.

Total Hours Worked

Total labor hours worked for all process plant operations during 1978 are shown in Table 8. The monthly total varied from 2,049.00 hr in November to 2,558.75 hr in March. Excluding the final 3 months, the minimum number of hours worked was 2,101.50 during September. Labor hours are classified by activity in Table 9.

Cleaning the process area required the greatest proportion of labor time, 3,978 hr (14.47%). Servicing the conveyors was second, accounting for 3,480 hr or 12.66%. Next was operating the end loader, which accounted for 2,831 hr (10.30%) and was necessary to feed the process and also to load nonprocessed metals. Landfilling labor was considerably higher in

TABLE 8. 1978 LABOR CLASSIFICATION BY ACTIVITY

Activity	Hr	%
Clean process area	3,978	14.47
Conveyors	3,480	12.66
End loader	2,831	10.30
Landfill	2,376	8.64
Tipping floor	2,331	8.48
Control room	1,589	5.78
Operations and grates	1,580	5.75
Secretarial and tours	1,474	5.36
General maintenance	1,379	5.02
Rejects	1,284	4.67
ADS	1,005	3.66
PSI	846	3.08
Shredders	494	1.80
Metals (nonprocessed)	471	1.71
Miscellaneous	452	1.64
Custodial	421	1.53
Combustion power	358	1.30
Fire	233	0.85
Hammers	185	0.67
Atlas bin	184	0.67
Dings magnetic separator	178	0.65
Paper baler	116	0.42
Electric room	101	0.37
Wood chips	68	0.25
Dust control	43	0.16
Disc screens	35	0.13
Total	27,492	100.02

TABLE 9. TOTAL HOURS WORKED

Activities	1976[a/] Hours	1976[a/] %	1977 Hours	1977 %	1978 Hours	1978 %	Total Hours	Total %
Operations and grates	2,684	20.65	1,642	5.91	1,580	5.75	5,906	8.65
Clean process area	2,185	16.81	5,688	20.47	3,978	14.47	11,851	17.36
End loader	1,545	11.88	2,832	10.19	2,831	10.30	7,208	10.56
Control room	1,192	9.17	1,977	7.11	1,589	5.78	4,758	6.97
Tipping floor	1,260	9.69	2,204	7.93	2,331	8.48	5,795	8.49
Secretarial and tours	525	4.04	1,304	4.61	1,474	5.36	3,303	4.84
Custodial	579	4.45	807	2.90	421	1.53	1,807	2.65
Rejects	476	3.66	1,208	4.35	1,284	4.67	2,968	4.35
Metals	252	1.94	422	1.52	471	1.71	1,145	1.68
(Dings)			9	0.02	178	0.65	187	0.27
Shredders	534	4.11	497	1.79	494	1.80	1,525	2.23
and hammers			340	1.22	185	0.67	525	0.76
General maintenance	453	3.49	1,445	5.20	1,379	5.02	3,277	4.80
Conveyors	104	0.80	2,258	8.13	3,480	12.66	5,842	8.56
Combustion power	204	1.57	1,045	3.76	358	1.30	1,607	2.35
ADS	389	2.99	749	2.70	1,005	3.66	2,143	3.14
PSI	41	0.32	1,301	4.68	846	3.08	2,188	3.20
Wood chips	98	0.75	154	0.55	68	0.25	320	0.47
Disc screens					35	0.13	35	0.05
Paper baler	70	0.54	733	2.64	116	0.42	919	1.34
Landfill	184	1.42	719	2.59	2,376	8.64	3,279	4.80
Dust controller					43	0.16	43	0.06
Miscellaneous	223	1.72	347	1.25	452	1.64	1,022	1.50
(Atlas)			12	0.04	184	0.67	196	0.29
Electric room					101	0.37	101	0.15
Fire			97	0.35	233	0.85	330	0.48
Total	12,998	100	27,790	100	27,492	100	68,280	100

a/ 1976 - Includes only June through December.

1978 than in 1977, 2,376 hr (8.64%), compared with 719 hr (2.59%) in 1977. This difference was largely the result of plant downtime for modifications which were made in October, November, and December. Other tipping floor labor included serving customers, operating the sweeper, and occasional hand sorting of hazardous items from incoming refuse. Together, these five activities accounted for 54.55% of the total labor required for all activities.

Controlling and monitoring processing equipment during normal operations required 5.78 and 5.75, respectively, or 11.53% of total labor. Nonprocessed metals required approximately 2.6 times as much labor as did processed metals. Most major items of processing equipment did not require sizable amounts of labor on an individual basis. The ADS and PSI systems required more labor than the shredders. Total labor hours for 1978 were practically identical to the total for 1977.

ELECTRICAL ENERGY UTILIZATION

Electrical energy required to operate the process plant and the storage bin is divided into major use categories in Table 10. These categories include primary and secondary shredding, the ADS blower, the pneumatic transfer blower, the storage bin, and an indirect category. The latter category includes energy required to operate all conveyors, elevators, and magnets as well as heating, lighting, and air conditioning for the process plant. It is significant that indirect usage is the largest category.

A considerable amount of energy is required for environmental control; for example, during the winter for heating. Methods of reducing energy

TABLE 10. ELECTRICAL ENERGY CONSUMPTION, 1978

	Primary shredder	Secondary shredder	ADS system	PSI system	Atlas bin	Indirect	Total	kwh/Mg
1st quarter, kwh/Mg	66,000	88,100	46,310	33,380	121,200	383,100	738,090	79.85
%	8.94	11.94	6.27	4.52	16.42	51.90	99.90	
2nd quarter, kwh/Mg[a]	22,800	38,700	29,390	13,120	44,960	78,040	227,010	63.90
%	10.04	17.05	12.95	5.78	19.81	34.38	100.01	
3rd quarter, kwh/Mg	80,500	96,000	63,990	49,640	127,320	215,000	632,450	59.29
%	12.73	15.18	10.12	7.85	20.13	33.99	100.00	
1st and 3rd quarter avg kwh/Mg	74,250	92,050	55,150	41,510	124,260	294,050	681,270	69.57
1st and 3rd quarter avg %	10.90	13.51	8.10	6.09	18.24	43.16	100.00	

[a] Missing May and June.

loss or obtaining it less expensively, such as by installing a steam line from the electrical power plant or by burning combustible rejects, warrant further investigation.

As in the case of the other 1978 data, the period from October through December is nonrepresentative because of the modifications which were being made at that time. Since problems with the metered data that made it unreliable were discovered in the second quarter, only data for the first and third quarters are included in the Table 10 averages.

As shown in the table, the secondary shredder required approximately 1-1/3 times as much energy as the primary shredder, 13.51% versus 10.90%. Reasons for this are not entirely clear, but there is evidence that both particle size and quantity of refuse influence the energy required to shred it. The addition of the disc screen system to remove sand, glass, and other material sufficiently small (38 mm or less) not to require secondary shredding should have an effect on the energy required. But the extent of the reduction of energy required for secondary shredding by this method is not certain since the glass and grit may assist the shredding process and at the same time cause hammer wear.

Reducing the energy required for secondary shredding was not the major basis for deciding on the need for a disc screen. The main justifications for the disc screen were reduction of abrasion and damage to the ADS and PSI systems and improved fuel quality.

The ADS and PSI systems consumed 8.10 and 6.09% of total electrical energy, respectively, based on the first and third quarters of 1978. These values are not much less than the value for the primary shredder despite the fact that motors for the ADS and PSI blowers are only 149.2 kW each (200 hp) compared with 746 kW (1,000 hp) for each of the two shredders. The two shredder motors, the ADS blower, and PSI blower were indirectly metered along with total plant usage. The difference between total plant usage and the sum of the four metered values is the indirect usage. This category includes all conveyors, elevators, air compressors, and fans plus all plant heating, lighting, and air conditioning. The average of the first and third quarters was 43.16%. Estimates calculated for the power used by all items in the indirect category was 694.58 kW, which is more than the combined total of power for the two shredders, the ADS, and PSI (609.39 kW). In deriving the estimate, actual kilowatts of energy consumed and plant running time in hours were used.

The second largest category of energy consumed was the Atlas storage bin, 18.24% of total energy for the processing, storage, and retrieval system. The energy required for material handling is one of the most energy intensive operations. Kilowatt-hours per megagram varied from 59.29 during the third quarter to 79.85 during the first quarter.

It is estimated that 1 Mg of incoming refuse to the process plant produces approximately 580 kWh of electrical energy in boiler unit Nos. 5 and 6. Since about 70 kWh are required to process 1 Mg of refuse in addition to storing and retrieving the 0.84 Mg of RDF typically derived from it, the solid waste recovery system yields approximately 8.3 times as much energy as is required to operate it. The economic aspects of energy utilization are discussed in Section 9.

PROCESSING AND DOWNTIME

During 1978, a total of 34,219 Mg of refuse were processed, resulting in 28,833 Mg of RDF (84.26%), 2,159 Mg of ferrous metal (6.31%), and 3,214 Mg of reject material (9.39%). A monthly production summary for the year is given in Table 11. Because of the disruption in production caused by plant modification during the last 3 months of the year, 9-month averages and percentages are given. While total and average quantities of RDF for the first 9 months differ from those for 12 months, it can be seen that relative percentages of materials as a fraction of incoming refuse are similar. In general, the proportions of materials derived from refuse have tended to vary little throughout the entire 3-year operating period.

Maximum production occurred during July when 3,366 Mg of refuse were processed. The least production for the first 9 months, considered to be representative of a full-time operating schedule, occurred during February when 2,594 Mg were processed. Average production for the first 9 months was 2,852 Mg, a value consistent with averages for the previous 2 years. RDF and ferrous metal production closely followed total refuse production.

RDF is clearly the most significant product. The economic significance of ferrous metal production from refuse is also discussed in another section. No aluminum or other nonferrous metal was produced during 1978. The wood chip and baled paper operations were negligible both in physical and economic terms.

TABLE 11. 1978 AMES SOLID WASTE SYSTEM - PRODUCT DISTRIBUTION IN TONS

Month	Tons processed	Electric power consumption (kwh)	RDF	Ferrous metal	Rejects	Wood chips	Baled paper
January	3,518.89	62.06	3,046.98	222.32	249.59	-	-
February	2,858.86	69.44	2,482.47	199.09	173.48	-	3.82
March	3,810.95	52.96	3,174.25	317.75	315.58	3.40	-
April	3,916.03	48.78	3,117.99	284.01	444.49	9.09	-
May	2,981.23	47.71	2,445.65	235.12	300.46	-	-
June	4,178.73	43.77	3,439.52	295.25	443.96	-	-
July	3,709.85	53.64	3,051.67	219.88	438.30	-	-
August	4,159.32	44.49	3,534.57	169.52	455.23	-	-
September	3,889.26	46.15	3,346.96	225.51	316.79	-	-
October	2,042.51	79.24	1,709.17	117.59	215,75	-	-
November	Plant did not operate - equipment installation						
December	2,954.25	71.15	2,374.04	93.77	186.44	-	-
12 month total	38,019.88	619.39	31,723.27	2,379.81	3,540.07	12.49	3.82
12 month avg	3,168.32	51.62	2,643.61	198.32	295.01	1.04	.32
1st 9 month total	33,023.12	469.00	27,640.06	2,168.45	3,137.88	12.49	3.82
1st 9 month avg	3,669.24	52.11	3,071.12	240.94	348.65	1.39	0.42

INDIVIDUAL SUBSYSTEM DATA

Pneumatic Conveying

The PSI system caused more downtime at the process plant than any other subsystem. Detailed data are given in Table 12. As can be seen, 9-month and 12-month data did not differ significantly. Total downtime for the year for the PSI system was 200.19 hr, and stoppage caused by high blower pressure and PSI pipeline pluggage accounted for 63.1 and 36.4%, respectively, of the downtime. High pressure occurred 333 times, totaling 126.31 hr during 1978; pipeline pluggage occurred 191 times, totaling 72.88 hr.

ADS System

The ADS system also caused a substantial amount of downtime--117.36 hr, 86.03 hr of which occurred during the first 9 months. The 9-month and 12-month data do not differ significantly. Principal causes of downtime were the ADS return air duct (C-99) with 33.16 hr; the air lock feeder, 23.12 hr; and conveyor C-7, 21.99 hr, which represent, respectively, 28.2, 19.7, and 18.7% of downtime. Flight breaking in the flight conveyor caused 12.41 hr or 10.6% of downtime. Other contributors had relatively little effect, the largest values being attributable to the vibrating screen (link belt) with 6.83 hr or 5.8% and the surge bin (scalping roll) and screw feeder, each with 6.3 hr or 5.4%. Details of the distribution of downtime throughout the year for components of the ADS system are given in Table 13.

TABLE 12. PNEUMATIC CONVEYING SYSTEM (PSI) DOWNTIME FOR 1978

Month	Air lock feeder	Blower	Pipeline	Miscellaneous
January	-	0.08	-	5.46
February	-	-	-	2.81
March	-	0.25	0.58	5.17
April	-	-	-	12.10
May	-	-	2.17	15.81
June	-	-	9.83	13.96
July	-	-	22.46	17.28
August	-	-	21.60	14.50
September	-	-	12.99	28.38
Total hours	-	0.33	69.63	116.57
9-month %	-	0.18	37.33	62.49
9-month avg	-	0.037	7.74	12.95
October	0.67	-	3.25	9.58
November	a/	a/	a/	a/
December	-	-	-	16
Total hours	0.67	0.33	72.88	126.31
12-month %	0.33	0.16	36.41	63.10
12-month avg	0.056	0.028	6.07	10.53

a/ No downtime. Plant was not in operation due to new equipment installation.

TABLE 13. ADS DOWNTIME FOR 1978

Month	Flight conveyer	Scalping roll (surge bin)	Channel-5	Vibrating screen (link belt)	Airlock feeder	Cyclone	Screw feeder	C-99 (return air)	Conveyor C-7	Miscellaneous
January	-	-	-	0.58	1.26	-	-	0.92	-	-
February	-	0.17	-	-	3.33	-	-	1.17	0.08	-
March	-	1.00	-	-	1.67	-	0.08	2.01	0.42	0.08
April	-	0.50	0.33	-	2.17	-	0.25	1.92	1.01	0.17
May	0.58	0.67	0.25	-	3.08	0.17	-	2.12	-	-
June	-	0.58	-	-	2.70	0.34	4.24	2.76	1.91	0.34
July	5.08	-	-	0.58	3.17	0.33	0.25	6.61	8.06	-
August	-	-	1.08	-	2.00	1.08	0.58	6.25	3.01	-
September	-	1.25	-	2.42	0.42	0.25	0.92	3.32	0.50	-
Total	5.66	4.17	1.66	3.58	19.8	2.17	6.33	27.08	14.99	0.59
9-month %	6.58	4.85	1.98	4.16	23.02	2.52	7.36	31.48	17.42	3.68
9-month avg	0.629	0.463	0.184	0.398	2.2	0.241	0.703	3.01	1.67	0.066
October	6.75	0.50	-	1.67	1.65	0.17	-	2.32	1.58	-
November	a/	a/	a/	a/	a/	a/	a/	a/	a/	a/
December	-	1.67	0.42	1.58	1.67	0.17	-	3.76	5.42	2.00
Total	12.41	6.34	2.08	6.83	23.12	2.51	6.33	33.16	21.99	2.59
12-month %	10.51	5.40	1.77	5.80	19.70	2.14	5.35	28.25	18.74	2.21
12-month avg	1.03	0.53	0.17	0.57	1.93	0.21	0.53	2.76	1.83	0.216

a/ No downtime; plant was not in operation due to new equipment installation.

Shredding System

Shredding system downtime totaled 108.04 hr during 1978, with 99.26 hr occurring during the first 9 months. Conveyor C-3 input hopper was plugged a total of 132 times, which caused 52.22 hr, or 48.3% downtime. Conveyor C-1 had broken pins, bolts, and links and also caused a circuit to trip several times. These events caused 34.89 hr, or 32.2% of shredding system downtime.

Other causes of downtime in the shredding system were relatively minor. These included conveyor C-5 which plugged 17 times for a total of 7.11 hr (6.7%) and hammer changes accounting for 10.66 hr, or 9.9% of downtime for both shredders combined. Detailed data for the year are listed in Table 14.

Ferrous System

The ferrous system was very reliable. Total downtime amounted to only 16.07 hr for the year, 15.82 for the first 9 months. Conveyor C-12 became jammed with loose metal 4 times and plugged 30 times for a total of 5.75 hr, 35.8% of downtime. Conveyor C-7A experienced jamming and plugging plus a broken belt on one occasion. Downtime for conveyor C-7A totaled 5.49 hr or 34.2%. Conveyor C-13 plugged 10 times for a total of 1.76 hr, or 11.0% of ferrous system downtime. Conveyor C-10 became plugged 10 times and jammed twice for 1.74 hr or 10.8%. The Dings magnet jammed 4 times and became misaligned in its tracking 3 times for a total of 1.33 hr or 8.3%. Details of downtime on a monthly basis are given in Table 15.

TABLE 14. SHREDDER DOWNTIME FOR 1978

Month	Primary shredder C-1 Conveyor	 C-3 Conveyor	 Hammers	 Fire	Secondary shredder Hammers	 C-5 Conveyor
January	6.21	0.49	-	0.25	-	0.25
February	9.17	0.25	4.0	-	6.0	5.62
March	1.76	1.74	-	0.58	-	0.25
April	1.81	5.69	0.08	-	-	0.08
May	1.04	1.83	0.58	1.17	-	-
June	0.50	1.49	-	0.33	-	-
July	3.72	3.40	-	0.50	-	0.08
August	2.56	32.51	-	0.25	-	-
September	3.25	1.74	-	-	-	-
Total	30.02	49.14	4.66	3.16	6.0	6.98
9-month avg	3.34	5.46	0.52	0.35	0.67	0.70
9-month %	30.24	49.51	4.69	3.10	6.04	6.33
October	2.95	0.99	-	-	-	-
November	-a/	-a/	-a/	-a/	-a/	-a/
December	1.91	2.09	-	-	-	0.83
Total	24.89	52.22	4.66	3.16	6.0	7.11
12-month avg	2.91	4.35	0.39	0.26	0.5	0.60
12-month %	32.30	48.28	4.33	2.89	5.55	6.66

a/ No downtime, plant was not in operation due to equipment installation.

TABLE 15. FERROUS SYSTEM DOWNTIME FOR 1978

Month	Dings magnet	C-7A	C-9	C-10	C-12	C-13
January	0.08	-	-	-	-	-
February	0.08	0.08	-	0.08	-	-
March	0.67	0.33	-	0.33	0.58	0.34
April	-	-	-	0.17	2.00	0.75
May	-	-	-	0.25	0.25	0.05
June	0.08	-	-	0.08	0.75	0.25
July	0.17	-	-	0.17	2.14	0.17
August	-	5.08	-	0.66	-	-
September	-	-	-	-	0.03	-
Total hours	1.08	5.49	-	1.74	5.75	1.76
9-month %	6.83	34.70	-	11.0	36.35	11.13
9-month avg	0.12	0.61	-	0.193	0.639	0.196
October	0.25	-	-	-	-	-
November	-a/	-a/	-a/	-a/	-a/	-a/
December	-	-	-	-	-	-
Total hours	1.33	5.49	-	1.74	5.75	1.76
12-month %	8.28	34.16	-	10.83	35.78	10.95
12-month avg	0.11	0.46	-	0.145	0.48	0.147

a/ Plant was not in operation due to new equipment installation.

RDF CONVEYING SYSTEM AND STORAGE BIN

The RDF conveying and storage bin systems include the 454 Mg Atlas storage bin plus the two pneumatic lines[a] which carry RDF to the power plant boilers. All RDF supplied to the electric power plant is first stored in the bin. It is retrieved from the bin by buckets on sweep drives and two drag conveyors.[a] The RDF is then broken up by pronged rollers known as fluffing rolls and is blown through the feed lines into the boilers. Thus, when the bin or boiler feed lines are inoperative, they can cause losses elsewhere in the system. When one or both feed lines to the power plant are being repaired, the power plant burns only coal, and the process plant can still operate and feed RDF into the bin. When mechanical problems occur in the bin, such as sweep or dragline failure, the process plant must stop processing to permit repairs. Thus, the process plant can experience downtime even when all its systems are fully operative simply because the bin cannot receive RDF. Other situations which force the plant to stop processing include fire in the bin or maintenance on both feed lines to the power plant occurring when the bin is full and therefore unable to receive any more RDF.

Process plant downtime caused by the storage bin was discussed above in this chapter in the subsection entitled, "Processing Plant Activities." Significant causes included sweep drive repair, refuse setting up in hard mounds, and a bin fire requiring complete clearing of all RDF from the bin.

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[a] Only two of four available units are currently used.

A total of 28,833 Mg of RDF were processed through the storage bin during 1978, an average of 2,792 Mg/month for the first 9 months of processing.

Calculation of downtime for the storage bin and pneumatic lines to the power plant is different than it is for the process plant. Since the power plant operates 24 hr/day, 7 days/week, and can burn RDF at any time, available time for the bin and pneumatic lines to the power plant equals the number of days per month multiplied by 24 hr. Operating time is equal to available time less the sum of idle time plus downtime. Idle time is that time when no RDF is entering the boiler because of problems with systems other than the bin or feed lines; for example, empty bin or ash line pluggage. Downtime is that period when no RDF is being sent from the bin to the boiler because of mechanical problems in the bin, fire in the bin, or pluggage of both pneumatic lines. Downtime for this system is shown in Table 16.

The left side of Table 16 summarizes available time, operating time, idle time, and downtime as defined in the preceding paragraph. The storage bin and boiler feed line system operated for a total of 5,668.55 hr, or 70.50% of available clock time in 1978. Problems external to the bin itself caused 1,881.82 hr of idle time, or 23.41% of available time. Downtime totaled 489.63 hr, or 6.09% of available time. No data are shown for November when the process plant did not operate and the bin had already been emptied of RDF accumulated during the first 2 weeks of October. The greatest amount of downtime occurred during May when extensive repairs were performed on the sweep drives.

TABLE 16. TIME DISTRIBUTION FOR 1978

	Atlas system				Pneumatic lines							
					Line A				Line D			
Month	Available time	Operation time	Idle time	Down-time	Available time	Operation time	Idle time	Down-time	Available time	Operation time	Idle time	Down time
January	744.0	553.93	128.04	62.03	553.93	542.50	-	11.43	553.93	527.85	-	26.08
February	672.0	477.58	189.87	4.55	477.58	474.02	-	3.56	477.58	423.33	-	54.25
March	744.0	579.00	159.25	5.75	579.00	561.55	-	17.45	579.00	544.33	-	34.67
April	720.0	612.03	107.14	0.83	612.03	583.58	-	28.45	612.03	573.98	-	38.05
May	744.0	511.58	38.50	193.92	511.58	494.62	1.66	15.30	511.58	501.85	4.25	5.48
June	720.0	550.25	140.50	29.25	550.25	522.2		22.33	550.25	542.67	5.00	2.58
July	744.0	486.65	168.75	88.60	486.65	474.42	-	12.23	486.65	485.52	-	1.13
August	744.0	595.32	100.70	47.98	595.32	575.18	-	20.14	595.32	591.74	-	3.53
September	720.0	475.77	197.73	46.50	475.71	473.57	-	2.20	475.77	472.35	-	3.42
October	744.0	423.86	309.92	10.22	423.86	418.16	-	5.40	423.86	380.55	15.33	27.98
November	-	-	-	-	-	-	-	-	-	-	-	-
December	744.0	402.58	341.42	-	402.58	383.83	2.83	16.92	402.53	387.82	-	14.77
Total	8,040.00	5,668.55	1,881.82	489.63	5,668.55	5,508.65	4.49	155.41	5,668.55	5,431.99	24.58	211.99
Percent	100%	70.50%	23.41%	6.09%	100%	97.18%	.08%	2.74%	100%	95.83%	0.43%	3.74%

The right side of Table 16 summarizes downtime for each of the two pneumatic feed lines to the power plant. Data for each line are shown independently. Available time for each line is defined as operating time for the storage bin. As in the left side of the table, operating time equals available time less the sum of idle time plus downtime. Idle time for each line is defined as that time when no RDF is flowing through the line into the boiler while the line is available for use. This occurs, for example, when only a small amount of RDF is in the bin and one line is sufficient to transport all RDF being used. Downtime occurs when the particular line is not delivering RDF because of pluggage, repair of worn elbows, or some other problem.

Lines A and D were both operating over 95% of available time. Line D experienced more idle time and downtime than line A. In both cases, however, downtime was under 5%. Line A was apparently used more often than line D when only one line was needed.

Labor hours, including supervision, required to operate the storage bin and pneumatic lines carrying RDF to the power plant can be classified as follows for 1978:

Allocation	Hours	Percent
Supervision	283.5	5.44
General system	453.5	8.70
Pneumatic lines	1,231.5	23.63
Storage bin	3,243.0	62.23
Total	5,211.5	100.00

These hours include time required for operations and maintenance. A monthly breakdown of these data are given in Table 15. Hours assigned to the pneumatic lines and to the storage bin vary widely from month to month. During February and May, sweep drives in the bin were being repaired.

A significant amount of labor was performed on the pneumatic lines in April and September. Both times, maintenance was performed on the lines while the bin was empty, and deslagging of boiler grates was being done on boiler unit Nos. 6 and 7. Sweep drive repairs occurred during July. In August, repairs were performed on the conveyors and air lock feeders which feed RDF to the lines. The bin floor was completely resurfaced during November.

The storage bin consumed an average of approximately 18% of the total electrical energy required to operate the entire solid waste recovery system including processing, storage, and retrieval. This is more energy than used in either shredding operation and more than twice as much as for air classification. The only single category of operational usage requiring more energy than the storage bin and boiler feed line system was the indirect category, at 43.6%. Material handling and transport of refuse and of RDF is energy intensive and yet adds no value to the material processed. Electrical energy requirements for the storage bin and boiler feed lines are relatively constant on the basis of kilowatt-hour per megagram.

SHREDDER MAINTENANCE

Hammer changes are scheduled on a nominal basis of once every 21,772 Mg (24,000 tons) for the primary shredder and once every 10,886 Mg (12,000 tons) for the secondary shredder. These changes are integrated into the plant maintenance schedule at the discretion of the plant manager. For the primary shredder, the average number of processing days between hammer changes during 1978 was 60.2 varying from 50 to 73 days. Hammers are turned at approximately half the change interval, since only one hammer face receives wear at a time. The primary indicator of a need to change or turn hammers is shradder clogging. Dates and change or turn intervals recorded for 1978 are as follows:

Date	Change or turn	Mg processed	Operating days
January 21	2 rows changed	12,176	61
February 10	2 rows changed	14,269	73
May 12	4 rows changed	10,746	57
August 9	2 rows changed	10,952	50
September 16	2 rows changed	4,746	26

For the secondary shredder, hammer changes and turns proceeded as follows during 1978:

Date	Change or turn	Mg processed	Operating days
February 24	changed 48 (4 rows)	6,965	40
May 16	changed 4 rows	9,748	48
August 29	changed 4 rows	13,250	65

MASS BALANCE

The absence of a gravimetric scale system for weighing the RDF burned in the boiler precludes the calculations of monthly mass flow rates. Thus, RDF production rates are determined by mass difference of input and output materials at the process plant.

At the refuse process plant, the amount of RDF sent to the Atlas storage bin is calculated as the difference between the total mass processed and the combined mass of recovered ferrous metal plus rejects which leave the plant: The mass of refuse processed includes the net weight of all commercial refuse haulers plus an estimated amount of refuse received from the private customers who dump material on the tipping floor from their private cars. Thus, total RDF mass delivered in 1978 was 28,833.3 Mg and includes the effect of plant shutdown for modification.

The mass of RDF burned in the boilers is accomplished by adjustment of a volume controlled delivery system at the Atlas bin to a setpoint for volume percent flow that is calculated from an estimated heating value and a density measurement for RDF in order to obtain a desired percent RDF heat input. The mass flow rate of RDF is by action of the operators in the power plant control room through use of the volumetric delivery system. This flow rate is monitored to provide some indication of the daily RDF consumption rates.

Estimates of daily RDF consumption in the boiler are obtained from calculation of integrated volume flow rates and several daily measurements of the RDF density. Comparison of the power plant RDF consumption corrected for estimated Atlas bin inventory with process plant RDF production rates has resulted in differences of up to 20%. Some of this error may be attributed to the impact of estimating car line mass flow rates, moisture loss in the process plant and the Atlas bin and wide variations in the density of the RDF delivered to the boiler.

Allocation of fuel credit for the mass burned is based on the equivalent heat released by the RDF as a replacement fuel and the subsequent reduction of the coal being burned. This calculation procedure and subsequent results are discussed in Section 9, Economic Evaluation.

SECTION 8

ECONOMIC EVALUATION

BACKGROUND

Economic and financial aspects of the Ames solid waste recovery system for 1978 are presented in this section. The first major subsection covers the initial capital investment needed to construct the process plant, storage bin, and pneumatic lines; modify the electrical power plant; and begin operations. These topics are discussed briefly. Readers desiring more detail are referred to the Year 1 Report for this project published in 1977.[1/]

The second major subsection describes economic operating experience for the calendar year 1978. This includes analysis and discussion of operating revenues and expenses and the economic impact of diverting refuse to the landfill during installation of the disc screen and dust collection systems.

It should be emphasized that only the first 9 months of 1978 can be considered representative from an operational standpoint. In the last quarter of the year, the plant operated at about 50% capacity during October and December and was shut down during November because of plant modifications. But the last 3 months did provide useful data on the economic value of refuse in terms of lost RDF and ferrous metal. Because the refuse was buried in the landfill, it was possible to determine the value of RDF in lost revenue estimated from the mass of buried refuse, as well as from the equivalent quantity of Iowa and Western coal normally saved when RDF is burned at the municipal power plant. The costs of operating the landfill which had been assigned to the process plant were also determined.

CAPITAL INVESTMENT

The initial investment in the solid waste processing plant, RDF storage bin, pneumatic lines, and power plant boiler modification was $6.3 million. A breakdown of these major capital expenditures is found in Table 17.

TABLE 17. ACTUAL CAPITAL INVESTMENT

System	Actual cost
Processing plant	$4,116,526
Pneumatic conveyors	164,388
Storage bin	551,292
Electrical	314,020
Boiler modification	178,988
Land	108,068
Engineering	376,896
Subtotal	$5,810,178
Minor equipment and start-up	486,405
Total investment	$6,296,583

Land

Land had been purchased prior to the project commitment. Also included in the cost of land were 10 acres of landfill and improvements such as adjacent streets and sewer lines. The inclusion of the cost of improvement as a part of land investment is a generally accepted accounting principle.

Start-Up Expenses

This category includes all operating expenses, training expenses, and interest incurred from the date operations began through December 31, 1975. The start-up cost totaled $321,578.

Plant and Equipment

This category is composed of three subclasses: actual processing equipment and conveyors; auxiliary equipment such as the front-end loader, tools, and spare parts; and the RDF storage bin, pneumatic lines and blowers, and firing equipment plus boiler modifications in the power plant. Equipment is thus classified according to its use in the systems.

Depreciation and Amortization

Internal Revenue Service general guidelines were used to establish depreciation schedules for major classes of capital equipment. Total annual depreciation was estimated at $353,878 or $29,490/month.

Engineering Design

Design of the Ames solid waste recovery system was based upon the size and needs of the community. In comparison with larger systems in existence, the Ames system represents a single complete modular process; that is, a series of operations which must be performed to obtain the materials produced from refuse. Larger systems such as those in Chicago and Milwaukee have duplicate parallel processes, each of which resembles the Ames process. Economies of scale have not yet been worked out for this type of system. One significant limiting factor is the relative capacities of the various subsystems operating in series. For example, the shredders in the Ames system can process at a rate of 45 Mg/hr, but the ADS system can only process at a rate that corresponds to a refuse infeed rate of 32 Mg/hr. During the 1978 operations, the refuse processing rate averaged 32 Mg/hr.

Design Costs and Actual Costs

In Table 18, costs estimated during plant design are compared with actual costs. The most significant differences shown are for minor equipment and start-up expense. With all operating expenses from August 30, 1975, to January 1, 1976, considered to be start-up expenses, the total estimated cost was exceeded by $737,583 or 13.3%, not unreasonable for a system based on new applications of technology. Much of the underestimate was the result of start-up expense which could not be predicted before the plant was constructed. Also contributing to the difference was the additional expended electrical work. The lack of appropriate information from equipment suppliers and the addition of electrical circuits both contributed to the underestimate. But when start-up expenses and electrical work are omitted, the actual total cost exceeds the estimated cost by only $151,158

TABLE 18. COMPARISON OF PLANNED AND ACTUAL COSTS

Capital investment	Estimated	Actual
Processing plant	$3,898,000	$4,116,526
Pneumatic conveyors	150,000	164,388
Storage bins	687,000	551,292
Electrical	114,000	314,020
Boiler modification	179,000	178,988
Land	156,000	108,068
Engineering	275,000	376,896
Subtotal	$5,459,000	$5,810,178
Minor equipment and start-up	100,000	486,405
Total investment	$5,559,000	$6,296,583

or 2.8%. Considering that estimated costs were projected over a 3-year period and that a 10% cost overrun is considered "normal" in major construction projects, the estimated investments are as accurate as could be reasonably expected.

ECONOMIC OPERATING EXPERIENCE

This subsection presents the financial aspects of operating the Ames solid waste recovery system. It should be recalled that the plant was operated in a limited capacity from October to December due to major plant modifications. Therefore, all revenues and plant operating costs are based on the first 9 months of the year. Revenues include those derived from the sale of recovered materials, the receipt of dump fees, and from the considerable credit allocation from the City of Ames for the sale of RDF to the municipally-owned electric power plant.

Operating expenses are discussed in terms of actual expenses and "per Mg of refuse received," the most accurate and consistent basis for relating cost to level of plant activity.

Operating Revenues

Revenues consist of income derived from the sale of recovered materials plus dump fees collected at the processing plant from private citizens, commercial haulers, and contract refuse haulers. Revenue data for the first 9 months of 1978 are shown in Table 19 on a monthly basis.

The major source of revenue was the sale of RDF, which amounted to $307,867.75, or 74.87% of all revenues received during 1978. The sale of RDF thus has an influential role in maintaining the economic viability of the entire solid waste recovery system. The contribution of RDF sales to total revenues is plainly evident in Tables 20 and 21 for the period 1976-1978. The 1978 fuel credit would likely have been comparable to the 1977 fuel credit value had it not been for the 10 weeks of downtime during the last 3 months of the year for plant modification. During 1978, fuel credit varied from $25,046.00 in May to $45,211.67 in April.

Revenue derived from the sale of RDF is based upon the estimated contribution of RDF to the total heat input at the power plant. Determination of this contribution is difficult for a number of reasons. First, the Ames power plant uses a bulk-density method of measuring the amount of RDF delivered to the power plant. Second, the combustion efficiency of RDF-coal mixtures is a function of many factors, some of which are still under

TABLE 19. OPERATING REVENUE FOR 1978
(1978 SOLID WASTE RECOVERY SYSTEM - DETAIL REVENUES)

Month	Metal sales	Wood chip sales	Public fees	Other regular customers	Paper sales	Fuel credit	Total monthly revenue
January	$ 4,786	$ 8	$ 685	$1,377	-	$33,314.29	$40,170
February	8,814	62	631	1,122	$248	29,799.17	40,676
March	6,777	-	1,085	1,167	461	44,002.62	53,492
April	9,170	80	1,078	981	568	45,211.67	57,088
May	10,771	120	1,178	1,241	-	25,046.00	38,356
June	7,979	129	1,269	1,202	-	31,648.00	42,227
July	10,551	76	1,110	1,244	-	26,992.00	39,973
August	245	29	1,765	1,326	-	36,897.00	40,262
September	17,288	148	1,094	1,210	-	34,957.00	54,697
TOTAL	$76,381	$652	$9,895	$10,870	$1,277	$307,667.75	$411,190a/
%	18.58	0.15	2.41	2.64	0.31	74.87	100

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a/ Added into Total Revenue $4,248.82 for insurance premium refund June 1978.

TABLE 20. SOLID WASTE PLANT--OPERATING REVENUES

Year	Revenue from sales of product Fuel credit ($)	Metal sales ($)	Wood chip ($)	Paper sales ($)	Tipping fee revenue Regular customer ($)	Public customer ($)	Total ($)
1976	319,453	101,070	2,240	1,876	12,648	11,434	448,721
1977	353,325	105,616	2,752	7,652	13,121	11,843	494,309
1978a/	307,867	76,381	652	1,277	10,870	9,895	411,190b/
Total	980,645	283,067	5,644	10,805	36,639	33,172	1,354,220

a/ January to September data only.

b/ Added into total revenues $4,248 for insurance premium refund June 1978.

TABLE 21. SOLID WASTE PLANT--OPERATING REVENUES DISTRIBUTION

Year	Fuel credit (%)	Metal sales (%)	Wood chip (%)	Paper sales (%)	Regular customer (%)	Public customer (%)	Total (%)
1976	71.19	22.52	0.50	0.42	2.82	2.55	100
1977	71.48	21.37	0.56	1.55	2.65	2.39	100
1978a/	74.87	18.58	0.16	0.31	2.64	2.41	100b/

a/ January to September data only.

b/ Insurance premium refunded in June 1978 included ≅1.03%.

investigation. Finally, the value of RDF is a direct function of the price of the Iowa and Western coal that it replaces.

After RDF, metal sales were the next largest source of revenue at $76,381, or 18.6% of the total. Regular customers and public fees amounted to 2.6 and 2.4% of total revenues, respectively. The sale of wood chips and baled paper had a negligible impact on operating revenues.

Tables 20 and 21 provide a classification of revenues for the 3-year period 1976-1978. The plant operated consistently during the entire period, and the relative amounts of revenue changed only slightly from year to year. Total annual amounts of revenues earned are a function of the quantity of refuse processed per year. Total annual revenues generated also depend upon prices received for RDF and ferrous metals.

Revenues for the first 9 months of 1978 totaled $411,190. During the same period, 29,958 Mg of refuse were processed, yielding 25,129 Mg of RDF and 1,967 Mg of ferrous metal. During this period, the total fuel credit was $307,867.75. Total ferrous metal sales were $76,381. This resulted in an average credit or price received equal to $12.25/Mg for RDF and $38.83/Mg for ferrous metal. Total revenues per megagram of all refuse received at the plant were $13.72. On a monthly basis, this value varied between $10.67 and $16.07/Mg.

Table 21 indicates that RDF and ferrous metals were consistently the major sources of revenue during the 3 years of plant operations and were the most important sources of revenue fuel credit. Revenues for ferrous metals are dependent upon market conditions and transportation costs.

Nonferrous metals have not yet had a significant effect on operating revenues.

Fees received from regular customers and from the public accounted for slightly more than 5% of revenues. Current tipping charges are $1.00 per commercial truck and $0.50 per automobile or pickup. Raising these tipping fees to a substantially higher level would increase plant revenue; however, the increased cost would still be borne by the public in higher fees for refuse hauling or disposing.

Monthly labor, energy, operating, and maintenance costs for the refuse processing plant and the RDF storage and retrieval costs for 1978 compared with megagrams of refuse received and operating cost per megagram are summarized in Table 22.

The operating and maintenance category includes contractual expenses to outside businesses providing services and commodities such as purchased parts, tools, and supplies. Salaries include all full-time and part-time employee wages, salaries for plant management, and a portion of the salaries of officials in the Ames Public Works Department, based on estimates of time allocated to the processing plant.

The monthly refuse processing cost varied from $17.84/Mg in August to $36.45/Mg in February; the yearly average was $26.19/Mg. The RDF storage cost varied from $2.72 to $4.63/Mg with an average of $2.89/Mg during the 1978 plant operations. The overall processing and RDF storage costs ranged from $20.59 to $39.79/Mg with an average of $29.09/Mg for the year.

TABLE 22. MONTHLY OPERATING EXPENSES AND COST PER Mg OF REFUSE RECEIVED

1978 Month	Labor cost ($)	Electrical energy cost ($)	Operating and maintenance cost ($)	Principal and interest ($)	Total process plant cost ($)	Total operations cost/Mg ($/Mg)	Total[a] storage and retrieval cost ($)	Total RDF storage and retrieval cost ($)	Refuse received (Mg)	Total processing and retrieval cost/Mg ($/Mg)
January	15,311	9,490	20,951	38,758	84,510	26.47	9,530	2.98	3,192	29.46
February	16,373	8,171	31,242	38,758	94,544	36.45	8,675	3.34	2,594	39.79
March	15,873	8,628	24,458	38,758	87,717	25.37	8,904	2.58	3,457	27.95
April	14,220	9,048	43,030	38,758	105,056	29.57	9,908	2.79	3,553	32.36
May	14,965	7,255	14,781	38,758	75,759	28.02	12,514	4.63	2,704	32.65
June	8,196	7,946	42,482	38,758	97,382	25.69	8,627	2.28	3,791	27.96
July	15,059	8,566	8,341	37,675	69,641	20.69	8,516	2.53	3,366	23.22
August	14,097	8,732	6,807	37,675	67,311	17.84	10,364	2.75	3,773	20.59
September	17,168	8,579	39,398	37,675	102,820	29.14	9,606	2.72	3,528	31.87
Total	131,262	76,415	231,490	345,573	784,740		86,644		29,958	
%	16.73%	9.74%	29.50%	44.03%	100.00%	26.19		2.89		29.09

[a] Includes all costs to operate the RDF storage and retrieval system.

It should be noted that the highest average processing costs were incurred when the plant processed the lowest volume of refuse, 2,594 Mg in February. Similarly, the lowest average processing cost occurred when the plant processed the largest quantity of refuse, 3,773 Mg in August. These results signal that the amount of refuse processed has a significant impact on plant economics, especially when one considers that the fixed cost of principal and interest payment accounted for 44.03% of the refuse processing plant's operating expenses.

Summary of Revenues and Expenses

Table 23 summarizes expenses for the process plant for 1976, 1977, and 1978. Total annual expenses remained relatively constant in that the decreasing principal and interest was approximately balanced by the increasing operating and maintenance costs.

Table 24 shows the relative percentages of operating and maintenance costs allocated to salaries, contractual expense, commodities, and principal and interest. Contractual expenses were higher than salaries for all three of the years. Principal and interest accounted for nearly half of the operating and maintenance costs. Total operating cost per megagram averaged $27.82 in 1976 and $23.87 in 1977. Net cost per megagram averaged $12.47 in 1978, compared with $15.73 in 1976 and $12.61 in 1977. These data are summarized in Table 25.

QUANTITY OF COAL REPLACED BY RDF IN 1978

During the 1978 operations, an equivalent of 11,414 Mg of coal was saved by burning RDF in the city's power plant to generate electrical energy.

TABLE 23. SOLID WASTE PLANT--OPERATING EXPENSES

Year	Operating and maintenance ($)	Principal and interest ($)	Total ($)
1976	512,194	520,992	1,033,186
1977	582,382	465,352	1,047,734
1978[a/]	439,167	345,573	784,740
Total	1,533,743	1,331,917	2,865,660

a/ January to September data only.

TABLE 24. SOLID WASTE PLANT--OPERATING EXPENSES DISTRIBUTION

	Operating and maintenance				
Year	Personnel (%)	Contractual (%)	Commodities (%)	Principal and interest (%)	Total (%)
1976	13.91	29.16	6.50	50.43	100
1977	18.91	24.40	9.21	47.48	100
1978[a/]	16.73	29.25	9.98	44.04	100
Average		53.52		46.48	100

a/ January to September data only.

TABLE 25. TOTAL OPERATING EXPENSES AND REVENUES FOR THE AMES SOLID WASTE RECOVERY PROCESSING PLANT 1976-1978

Year	Total operating expense ($)	Total revenue ($)	Total net cost ($)	Refuse processed (Mg)	Total cost/Mg ($/Mg)	Net cost/Mg ($/Mg)
1976	1,033,186	448,721	584,465	37,137	27.82	15.73
1977	1,047,734	494,309	553,425	43,890	23.87	12.61
1978[a/]	784,740	411,190	373,550	29,958	26.19	12.77

a/ January through September only.

energy. The monthly effective heat input of the fossil and RDF fuels is listed on Table 26. The table also shows the monthly amount of RDF consumed and the RDF fuel credit received.

In 1978, RDF fuel credit accounted for $363,069. The RDF fuel credit is determined in the following manner. The gross kilowatt-hour generation is multiplied by the heat rate (MJ/kW/hr) for coal only for the average monthly load to give the total effective heat input, megajoules. That is, total heat in MJ = (kW/hr) (heat rate, for coal only). The effective coal heat input is determined by multiplying the average coal heating value and the total quantity of coal burned. The total RDF effective input heating value is the difference between the total effective heat input and the total effective coal heat input for the month. The RDF fuel credit is calculated

TABLE 26. RDF CREDIT CALCULATIONS FOR 1978

Month 1978	Total (MJ)	Effective heat input[a] fossil fuel[c] (MJ)	RDF (MJ)	RDF[b] burned (Mg)	RDF effective avg heating value (kJ/kg)	RDF credit ($)
January	70,896,909	45,093,508	25,803,401	3,072	8,399	33,314.29
February	66,145,968	42,267,620	23,878,348	2,231	10,704	29,799.17
March	136,316,128	103,308,688	33,007,440	3,107	10,622	44,002.62
April	175,362,944	144,871,482	30,491,462	2,950	10,336	45,211.67
May	212,703,403	194,161,145	18,542,680	2,446	7,580	25,046.00
June	222,888,259	198,045,655	24,843,140	2,988	8,313	31,648.00
July	252,994,275	232,981,980	20,012,295	3,018	6,631	26,992.00
August	261,211,670	232,818,455	28,393,215	3,043	9,331	36,897.00
September	244,283,140	217,085,240	27,197,900	3,104	8,761	34,957.00
October	230,169,350	206,930,865	23,238,485	2,004	11,597	30,617.00
November[d]	----	----	----	----	----	----
December	232,100,000	213,770,430	18,329,570	1,767	10,371	24,584.00
Total	2,105,073,150	1,831,335,465	273,737,685	29,731	9,207[e]	363,069.00

[a] Effective heat input values are as reported by the power plant.

[b] RDF quantity adjusted for inventory in the RDF storage bin as reported.

[c] Fossil fuel includes coal, fuel oil, and natural gas.

[d] Refuse processing plant shut down for modification.

[e] Average value for 12-month period.

by multiplying the total effective value of the RDF times the monthly average cost ($/MJ) of comparable fuels (coal, fuel, oil, and natural gas). The effective RDF heating value is determined by dividing the RDF effective heat input into the best estimate of RDF burned (Mg). These calculations are shown in Table 27.

Burning RDF causes lower boiler operating efficiency for a given load than when coal is burned alone. That is, the boiler's heat rate is increased more than when only coal is used to generate the same load. As a result, a penalty is assessed RDF for causing lower boiler operating efficiency than coal. It should be noted that, at low boiler turbine loads, igniters which use fuel oil and natural gas are turned on in order to maintain burner flame stability.

Coal prices have risen sharply during the past 3 years. In 1976, Iowa coal cost $18.90/Mg; and in 1978, $20.72/Mg. Western coal from Colorado and Wyoming cost $27.16/Mg in 1976 and $37.88/Mg in 1978.

Assuming the continued usage of approximately 55% Iowa coal and 45% Western coal, and of similar price trends in the future, the value of RDF will increase substantially.

Trends in coal prices for the yard-delivered coal price per megagram of Iowa and Western coal between 1974 and 1979 are as follows:

TABLE 27. CALCULATIONS FOR THE AMOUNT OF COAL SAVED DUE TO BURNING OF RDF IN 1978

a. Effective RDF heat input (January to December 1978)

$$Q = 273{,}737{,}685 \text{ MJ from RDF}$$

b. Iowa and western coal characterization

1. Average heating values

Iowa coal	22,328 kJ/kg
Western coal	25,352 kJ/kg

2. Proportion of Iowa and western coal used in boiler

Iowa coal	45.32%
Western coal	54.68%
Total	100.00%

3. Iowa and western coal composite heating value

$$Q \text{ composite} = \left(\frac{22{,}328 \text{ kJ}}{\text{kg}}\right)(0.4532) + \left(\frac{25{,}352 \text{ kJ}}{\text{kg}}\right)(0.5468)$$

$$= 23{,}982 \text{ kJ/kg}$$

c. Equivalent quantity of coal replaced by RDF

1. Total coal replaced $= 273{,}737{,}685 \text{ MJ} \times \frac{1 \text{ kg}}{23{,}982 \text{ kJ}} \times \frac{1 \text{ Mg}}{1{,}000 \text{ kg}}$

$$= \underline{\underline{11{,}414 \text{ Mg}}} \longleftarrow$$

Year	Price per Mg ($)		Colorado coal ($)
	Iowa coal	Wyoming coal	
1974 (first 6 months)	11.35	17.05	
(last 6 months)	12.92	20.81	
1975 (first 6 months)	18.08	22.68	
(last 6 months)	18.90	24.58	
1976 (first 6 months)	18.90	26.06	
(last 6 months)	18.90	27.16	
1977 (first 6 months)	18.90	29.49	35.84
(last 6 months)	18.90	35.84	
1978 (first 6 months)	19.29	37.65	37.88
(last 6 months)	22.16	38.10	
1979 (first 6 months)	26.20	39.47	

ECONOMIC IMPACT OF DIVERTING REFUSE TO LANDFILL

Refuse Diverted to Landfill Due to Plant Downtime

Approximately 10 weeks of downtime occurred from October 23 to December 11, 1978 because of installation of the disc screen and dust collection systems. During this period, all refuse was hauled to the landfill, resulting in the loss of all revenue from the sale of refuse-derived materials. These losses were estimated by recording packer truck numbers at the landfill for all arrivals and using an average of five known tare weights for each truck obtained from its previous history of weighings on the scale at the processing plant. Historical data were used to estimate the amounts of RDF and ferrous metal that would have been derived from the refuse and sold. Losses in revenue for the last 3 months of 1978 were estimated as follows:

Month	Downtime (days)	Revenue loss ($)
October	9	18,620
November	21	29,370
December	10	15,000

Refuse was also hauled to the landfill at other times when the plant was not operating. Revenue losses during these times depended upon the length of the downtime periods and the capacity of the processing plant to receive incoming refuse on the tipping floor when downtime occurred. Data for the entire year are shown in Table 28. During 1977, lost revenue totaled $20,390. During the first 9 months of 1978, lost revenue totaled $32,990.

Landfill Operations

The city's landfill located 2 miles from the refuse processing plant accepts nonrecyclable materials from various customers. Customers and the types of materials they discard are shown in Figure 16. Demolition materials are unloaded at a separate area in the landfill and buried weekly. The remaining materials received at this landfill are unloaded in another area adjacent to the demolition discarding area and are buried daily. The landfill operating expenses are shared by the landfill users based on the proportion of material discarded by each user. The refuse processing facility uses the landfill to dispose of its rejected materials and unprocessed refuse when the facility is unable to process the incoming refuse.

TABLE 28. DOWNTIME AND REVENUE LOSS FOR 1978

Month	Days downtime	Revenue loss
January	1	
February	2	
March	3	$ 1,140
April	4	5,700
May	7	12,330
June	1	2,500
July	-	3,530
August	-	3,500
September	-	4,290
October	9	18,620
November	21	29,370
December	10	15,000
Total		$95,980

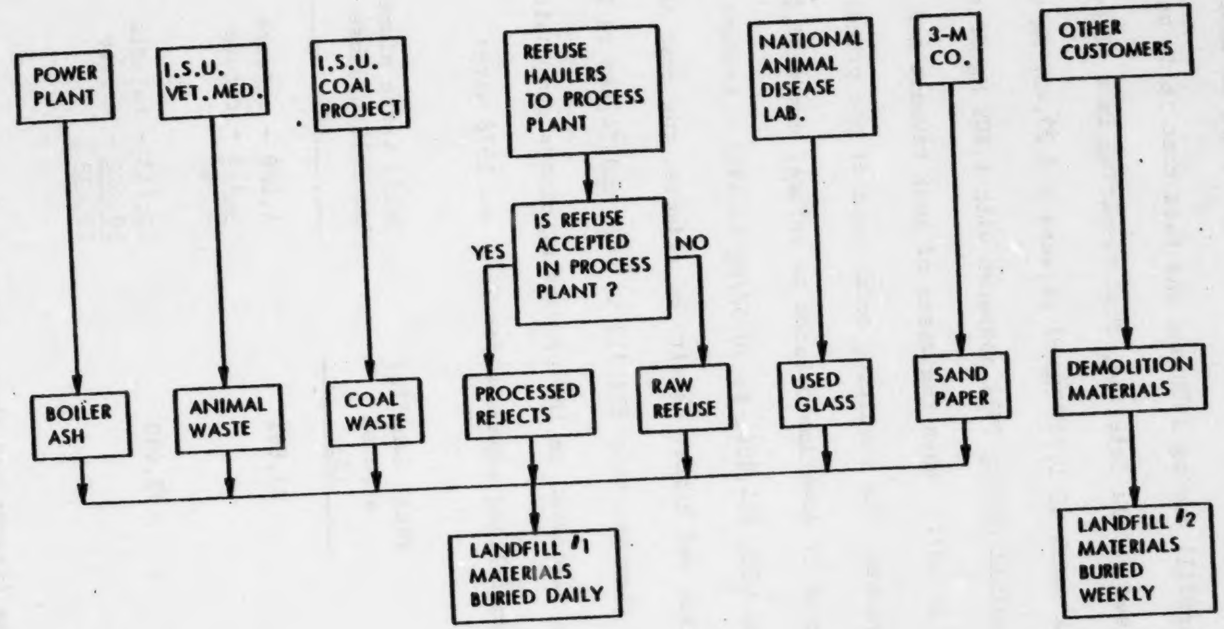
POWER PLANT
I.S.U. VET. MED.
I.S.U. COAL PROJECT
REFUSE HAULERS TO PROCESS PLANT
IS REFUSE ACCEPTED IN PROCESS PLANT ?
YES
NO
NATIONAL ANIMAL DISEASE LAB.
3-M CO.
OTHER CUSTOMERS
BOILER ASH
ANIMAL WASTE
COAL WASTE
PROCESSED REJECTS
RAW REFUSE
USED GLASS
SAND PAPER
DEMOLITION MATERIALS
LANDFILL #1 MATERIALS BURIED DAILY
LANDFILL #2 MATERIALS BURIED WEEKLY

Figure 16. The Ames landfill process flow chart as of the year 1979.

The cost per megagram for landfilling was nearly 10 times as high in 1978 as in 1977 because of the large amount of unprocessed refuse hauled to the landfill during 1978 and the fact that it is only ~43% as dense as processed refuse rejected, thus resulting in a higher charge per volume buried. A total of 1,757 Mg of rejects and 20,437 Mg of refuse was buried in the landfill during 1978 compared with 1,809 Mg of rejects and 4,148 Mg of refuse in 1977. When the costs of lost revenue and landfilling of refuse are combined, the resulting total cost of not processing refuse, or the total cost of downtime related to refuse, was $155,202, or $4.54/Mg in 1978 compared with $24,934, or $0.57/Mg in 1977. Because of the relatively small mass and higher density of rejects, the cost associated with landfilling them was only $12,913 in 1978 and $4,889 in 1977. Landfilling expenses allocated to the processing plants and their proportion of the total landfilling expenses for 1977 and 1978 were:

Year	Total landfill expense ($)	Solid waste plant landfill expense ($)	% of Total
1977	23,861	4,889 - rejects	
		4,471 - refuse	
		9,360	39.23
1978	93,680	12,913 - rejects	
		59,222 - refuse	
		72,135	77.0

These figures and those given in the preceding discussion quantify the importance of minimizing downtime at the processing plant. The fact that downtime can never be totally eliminated and can occur over sizable intervals underscores the need for maintaining a landfill as a standby disposal system.

Landfill Operating Expenses

Costs of operating the landfill which were assigned to the solid waste plant during the first and last 6 months of 1978 for handling rejects and unprocessed refuse were as follows:

Period	Reject cost ($)	Refuse cost ($)
January-June	8,123.52	18,077.80
July-December	4,789.07	41,144.96
Total	12,912.59	59,222.76

The total of all landfilling costs assigned to the solid waste processing plant during 1978 was $72,135.35. When added to the cost of lost revenue, the resulting total cost of downtime is very significant. The last 3 months of 1978 are considered unrepresentative of ordinary operating conditions.

Landfilling costs are assigned to the user based upon cubic yards deposited as a fraction of total cubic yards deposited multiplied by the total cost of operating the landfill for a given 6-month period.

Costs to the solid waste plant for landfilling during 1977 and 1978 were as follows:

Year	Type of refuse	Quantity (Mg)	Total cost ($)	Average cost ($/Mg)
1977	Reject	1,809.45	4,889	2.70
	Refuse	4,148.00	4,471	1.08
Total		5,957.45	9,360	1.57
1978	Reject	1,757.14	12,913	6.95
	Refuse	20,437.45	59,222	2.90
Total		22,194.59	72,135	3.25
1977-1978 Total		28,152.04	81,495	2.89

Distribution of operating expenses for the City of Ames landfill from 1977 through early 1979 was as follows:

Period	Personnel ($)	Contractual ($)	Commodities ($)	Total ($)
July-December 1977	1,053	14,198	11	15,262
January-June 1978	1,487	37,022	1,118	39,627
July-December 1978	5,408	47,938	707	54,053
January-March 1979	1,334	11,728	43	13,105

Contractual expenses include those for earthmoving by contractors when city-owned equipment is unavailable or inadequate. Landfilling large amounts of refuse is expensive and is even more expensive when the addition of lost revenue is considered in terms of salable products that could have been derived from processed refuse. Landfilling expense also adds to the total, the actual cost of downtime for the processing plant, thus raising the cost of materials derived from processed refuse. There are many factors to consider in examining the process plant-landfill tradeoff. These factors are unique for a given community plant process, material recovery transport and marketability, and landfill economics. In any case, the economic impact of landfilling is not negligible.

SECTION 9

FLOW STREAM CHARACTERIZATION

INTRODUCTION

A major task of the 3 year study of the Ames solid waste processing plant was a 1 year long study to characterize the waste material at various locations throughout the flow stream. The objectives of this task were to identify specific parameters of the flow stream waste such as material composition, bulk density, size distribution, chemical analysis, heating value and moisture; utilize the data to determine how effectively the equipment was operating, and how each process step impacted the other equipment and the final product (RDF); and to identify any seasonal effects on the material or the processing equipment.

A flow stream characterization sampling program was conducted from July 5, 1977, through July 13, 1978, which was prior to the modifications of the plant that included the addition of a grit removal system. A second flow stream characterization study was conducted from February 26 to April 16, 1979, to determine the difference in the processing operation and RDF after the plant modifications were completed. The results of the second study and a comparison with the first are presented in Section 11.

The sampling for both studies were conducted at various locations described in Section 9.

Continuous wear of shredder hammers will produce changes in sizing and bulk density properties. Thus, monitoring of these two parameters could indicate the wear and perhaps provide a warning that hammers should be changed before a rapid deterioration in quality occurs. This latter effect would change the performance of the ADS and the amount and quality of combustible material produced.

Variation in sizing of material sampled only at the ADS inlet and outlets can indicate the hammer wear and the potential need for their replacement.

Bulk density for conveyor C-11 is very low, 61.50 kg/m^3, the lowest of all the bulk density values.

Conveyor C-12 has a bulk density value of 252.16 kg/m^3, which is relatively high compared to the other bulk density values already discussed. C-12 consists mainly of ferrous material which was magnetically separated from C-10. The explanation for such a high bulk density value is because the material has been magnetically separated twice and contains 98.12% ferrous material.

Conveyor C-13, the total ferrous material recovered, has a relatively high bulk density value of 299.65 kg/m^3 and is 95.75% ferrous material.

It is most interesting to note that the bulk density for the heavies ferrous chute has the largest measurement of 632.23 kg/m^3 of all the bulk density values. The chute consists of 68% ferrous material which is conveyed and magnetically separated, thus feeding the ferrous chute and ending up in ferrous storage. The explanation for such a high bulk density value is due to the fact that material which feeds the chute is high in metal and grit content and relatively small in particle size, thus having a high mass-to-area ratio which tends to be high in density flow. The same logic is also applied to both elevator E-1 and conveyor C-15, because the bulk density values were relatively high with E-1 at 411.74 kg/m^3 and C-15 at 405.94 kg/m^3.

PROCESS SHREDDING SYSTEM

The size reduction takes place in two shredders staged to progressively reduce size to final nominal 38 mm (1-1/2 in.) particle size. The primary shredder processes the raw refuse using 70 kg hammers and grate bar openings of 227 mm (9 in.) square. As the material is discharged from the primary shredder, it passes under a Dings magnet belt system for major ferrous metals removal. Then the material is conveyed to the second shredder for final size reduction which is accomplished using 20 kg hammers and 76 by 127 mm (3 by 5 in.) rectangular grate bar openings.

Primary Shredder

The sizing distribution of the material discharged from the shredder is shown in Figure 17. It is seen that about 25% of the material is larger than 64 mm while 15% is smaller than 2 mm. The bulk density is found to average 100 kg/m^3.

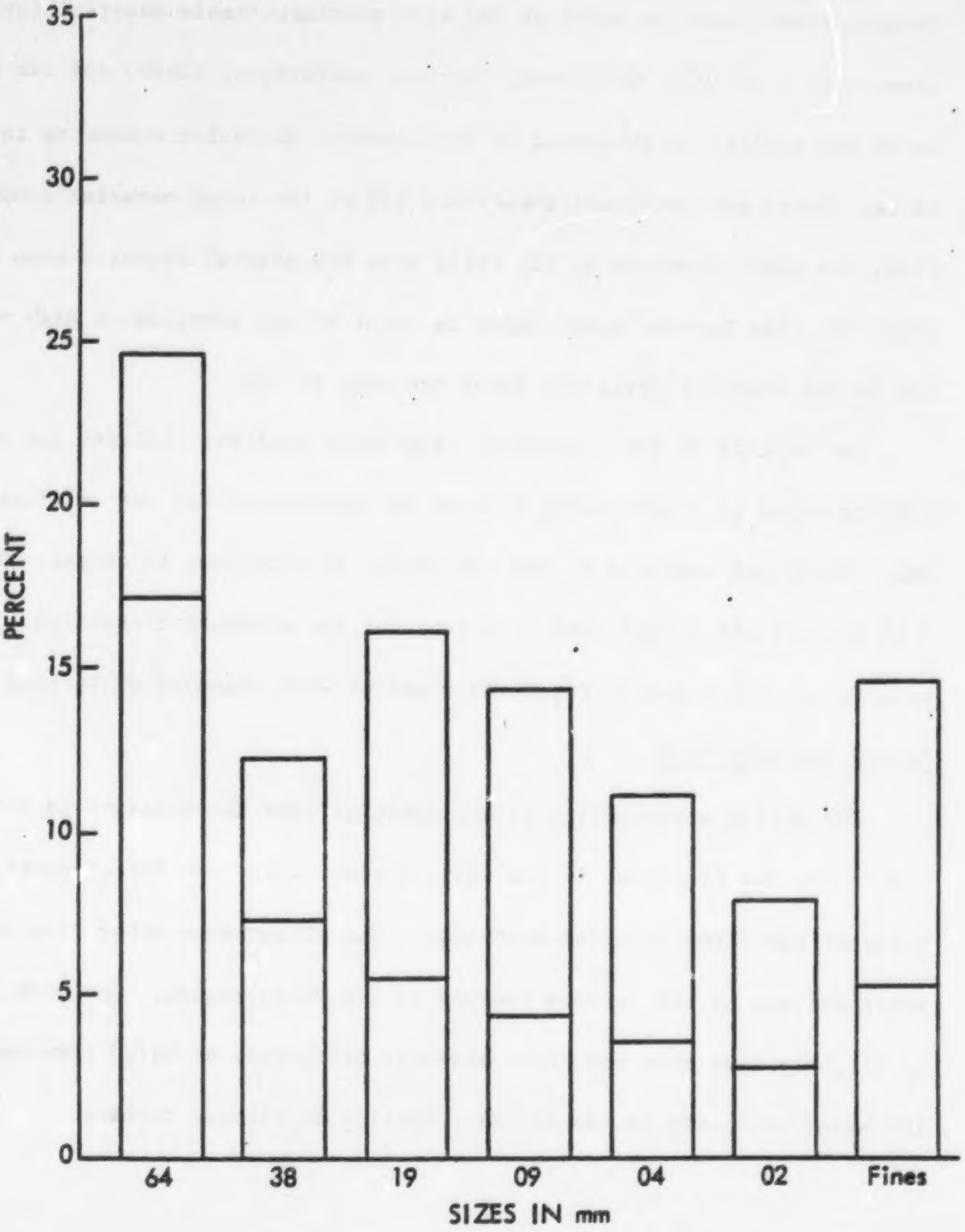

Figure 17. Primary shredder discharge (C-2); size distribution.

Composition of the material is shown in Figure 18. It is seen the largest constituent is paper at 34% with nonclassifiable material (grit, stone, etc.) at 19%. Cardboard, ferrous, nonferrous, cloth, and tar exhibit large variability as evidenced by the standard deviation exceeding the mean value. Paper and cardboard constitute 46% of the input material composition; the glass fraction is 9%, while wood and natural organics each comprise 7%. The ferrous metal input is about 6% and experiences high variability as one standard deviation about the mean is 13%.

The results of the analytical laboratory analysis indicate the average heating value is 11,300 kJ/kg with an ash content of 23% and moisture at 24%. Elemental analysis of the ash yields 5% aluminum, 1% copper, 3% iron, 0.2% lead, 0.06% nickel, and 0.3% zinc for the elements classified. These results are displayed in Figure 19 together with standard deviations.

Second Shredder Feed

The sizing distribution of the material into the shredder is shown in Figure 20; the fractions in the various size ranges are fairly close to those of the first shredder discharge. The differences other than sampling error are due to the ferrous removed by the Dings magnet. The bulk density is slightly less than the first shredder discharge; 95 kg/m^3 compared to 100 kg/m^3 which may be due to the reduction in ferrous content.

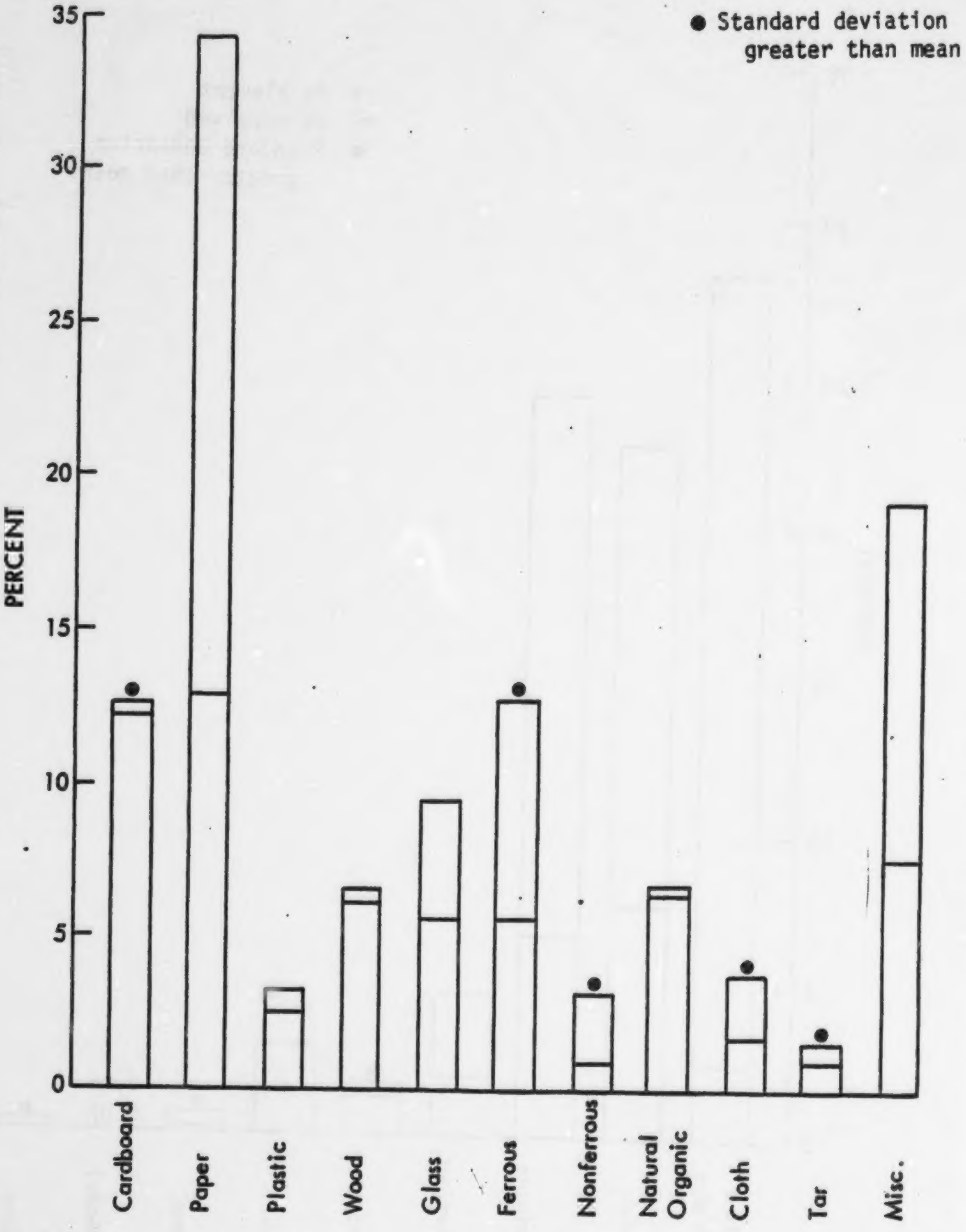

Figure 18. Primary shredder discharge (C-2); composition.

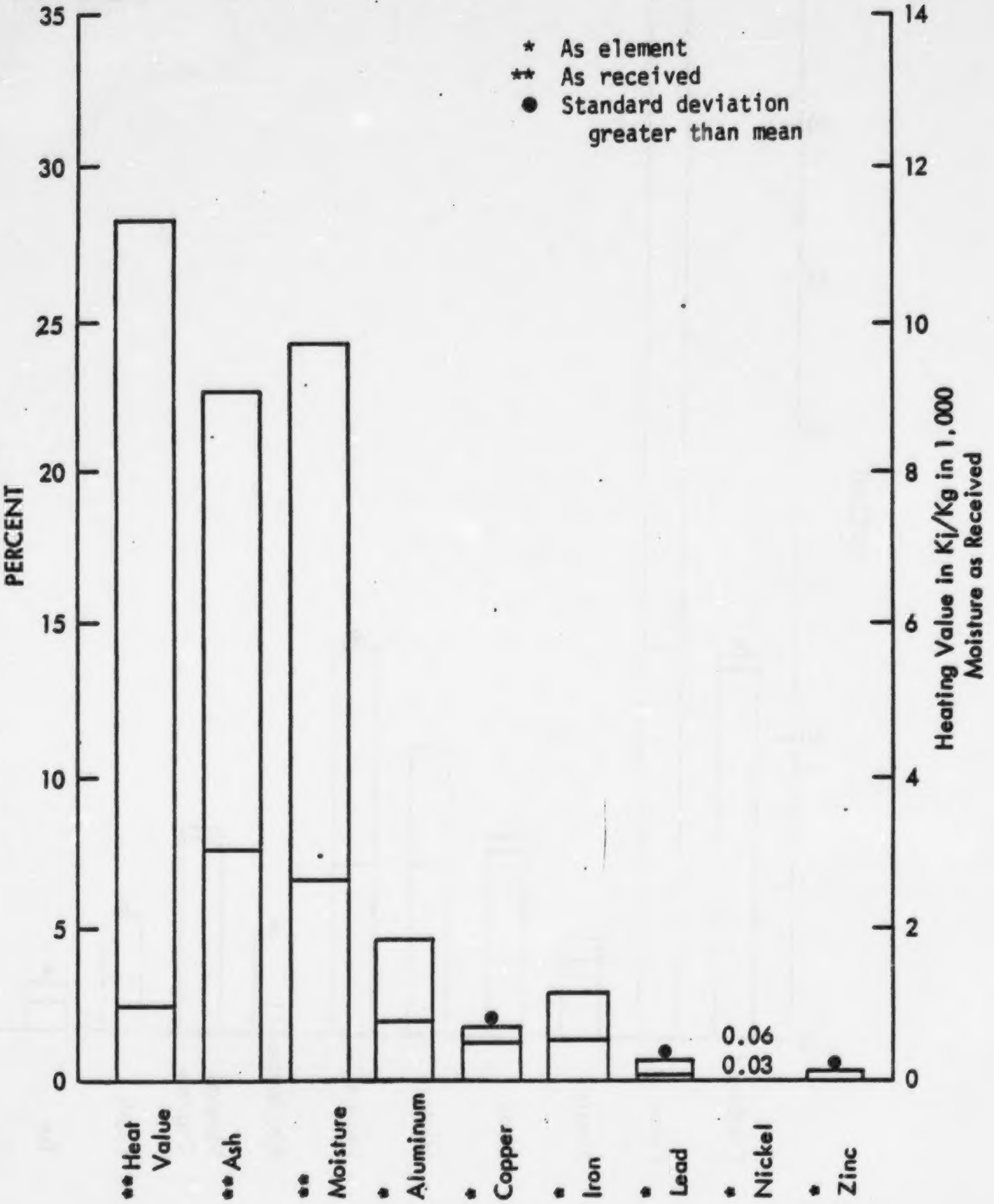

Figure 19. Primary shredder discharge (C-2); laboratory analysis.

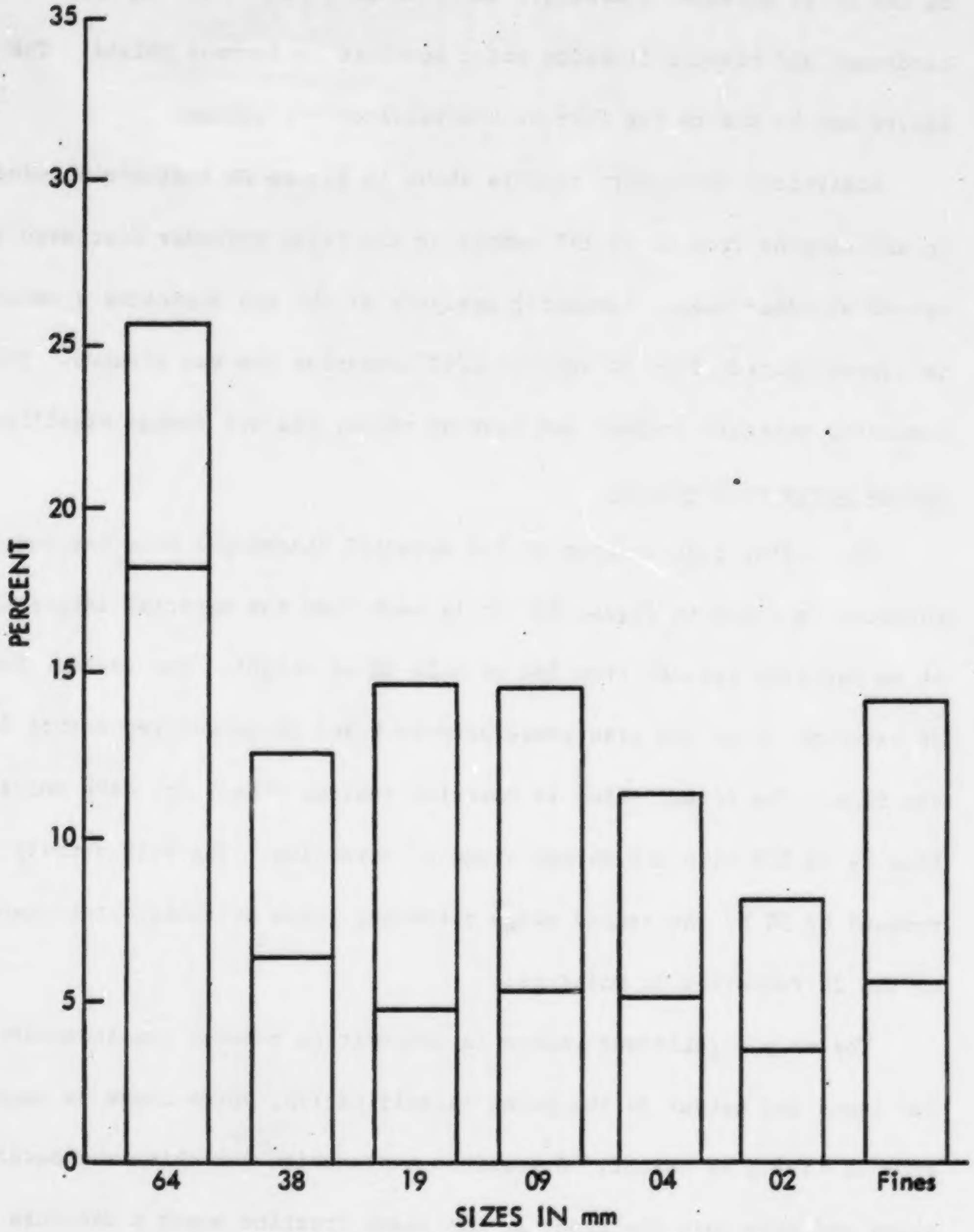

Figure 20. Secondary shredder input (C-3); size distribution.

Characterization of the input material is shown in Figure 21; compared to the first shredder discharge, there is somewhat of an increase in the cardboard and plastic fraction and a decrease in ferrous metals. These shifts may be due to the ferrous removal from the stream.

Analytical laboratory results shown in Figure 22 indicate a reduction in ash content from 22 to 19% comparing the first shredder discharge and second shredder feed. Elemental analysis of the ash indicates a reduction in copper content from 1% down to 1/4% comparing the two streams. The other elements, moisture content and heating value, did not change significantly.

Second Shredder Discharge

The sizing distribution of the material discharged from the second shredder is shown in Figure 23; it is seen that the material larger than 64 mm has been reduced from 26% to only 4% by weight. The largest fraction of material is in the size range between 9 and 19 mm and represents 23% of the flow. The fines, which is material smaller than 2 mm, have increased from 14 to 20% with the second stage of shredding. The bulk density is reduced by 3% by the second stage shredding which correlates reasonably well to the 2% reduction in moisture.

The only significant change in composition between the secondary shredder input and output is the paper classification, which shows an increase from 32 to 39% by weight. A possible explanation for this is embedding of glass and grit into the paper as the glass fraction shows a decrease from 9% down to 5%. Composition results are displayed in Figure 24.

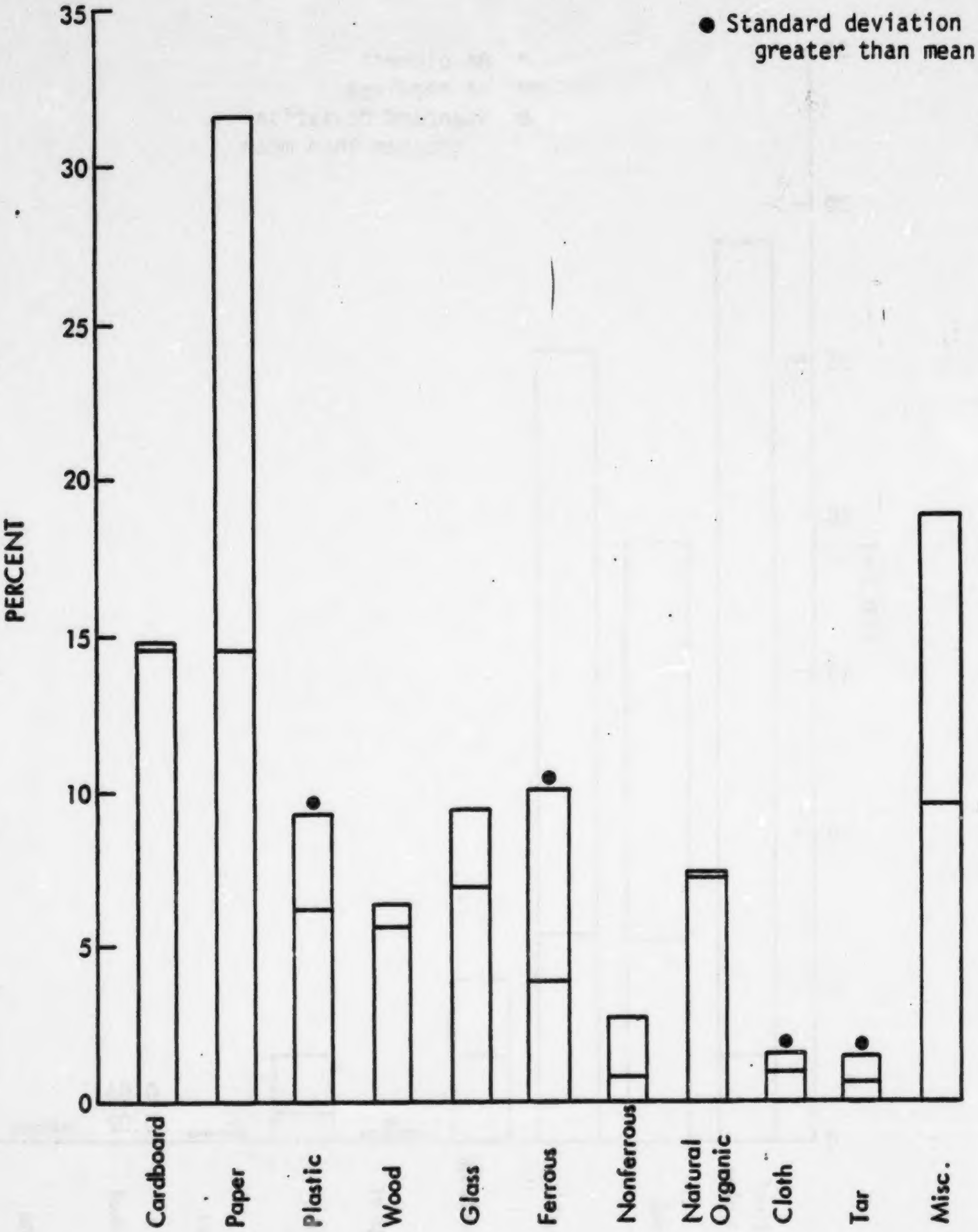

Figure 21. Secondary shredder input (C-3); composition.

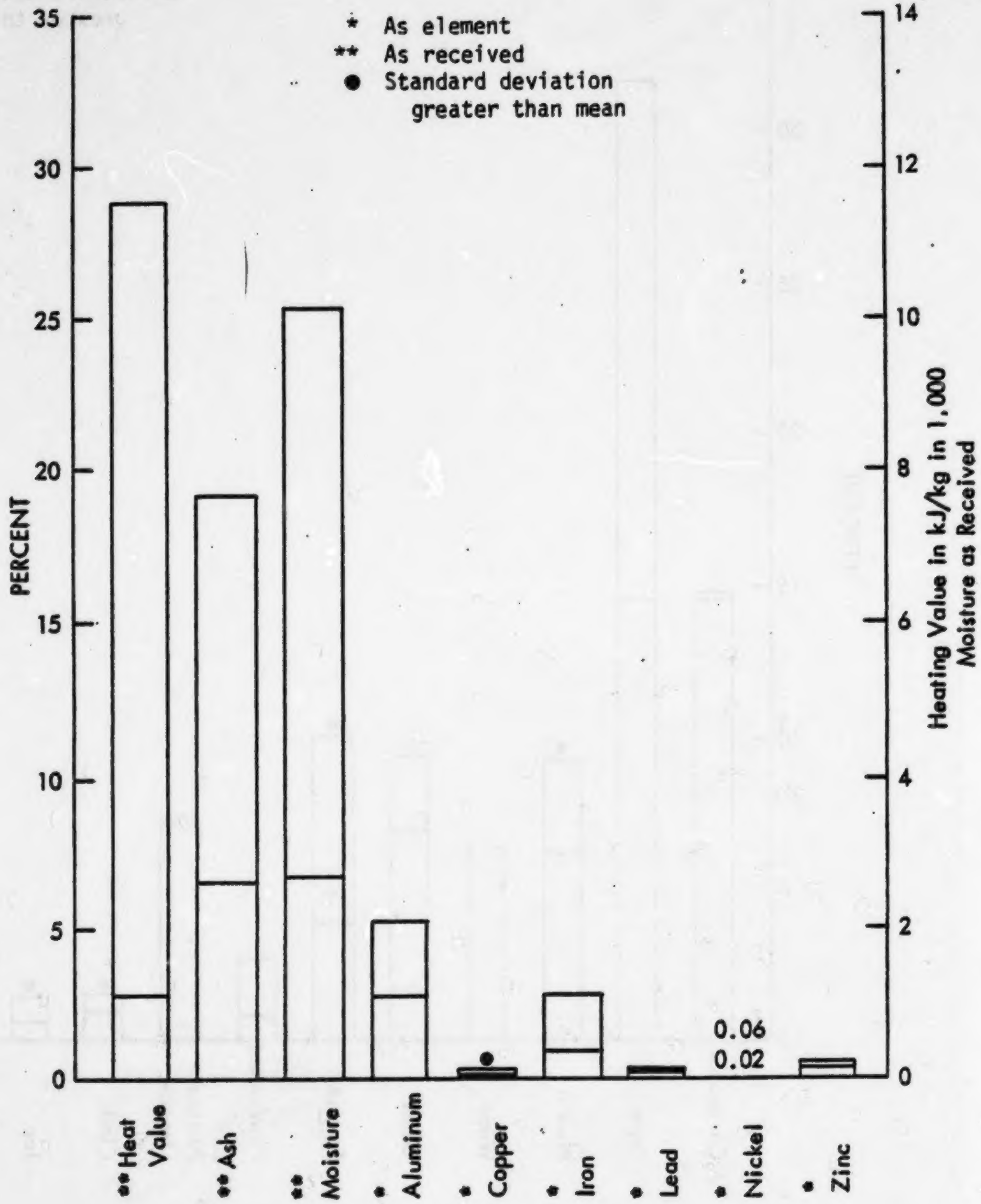

Figure 22. Secondary shredder input (C-3); laboratory analysis.

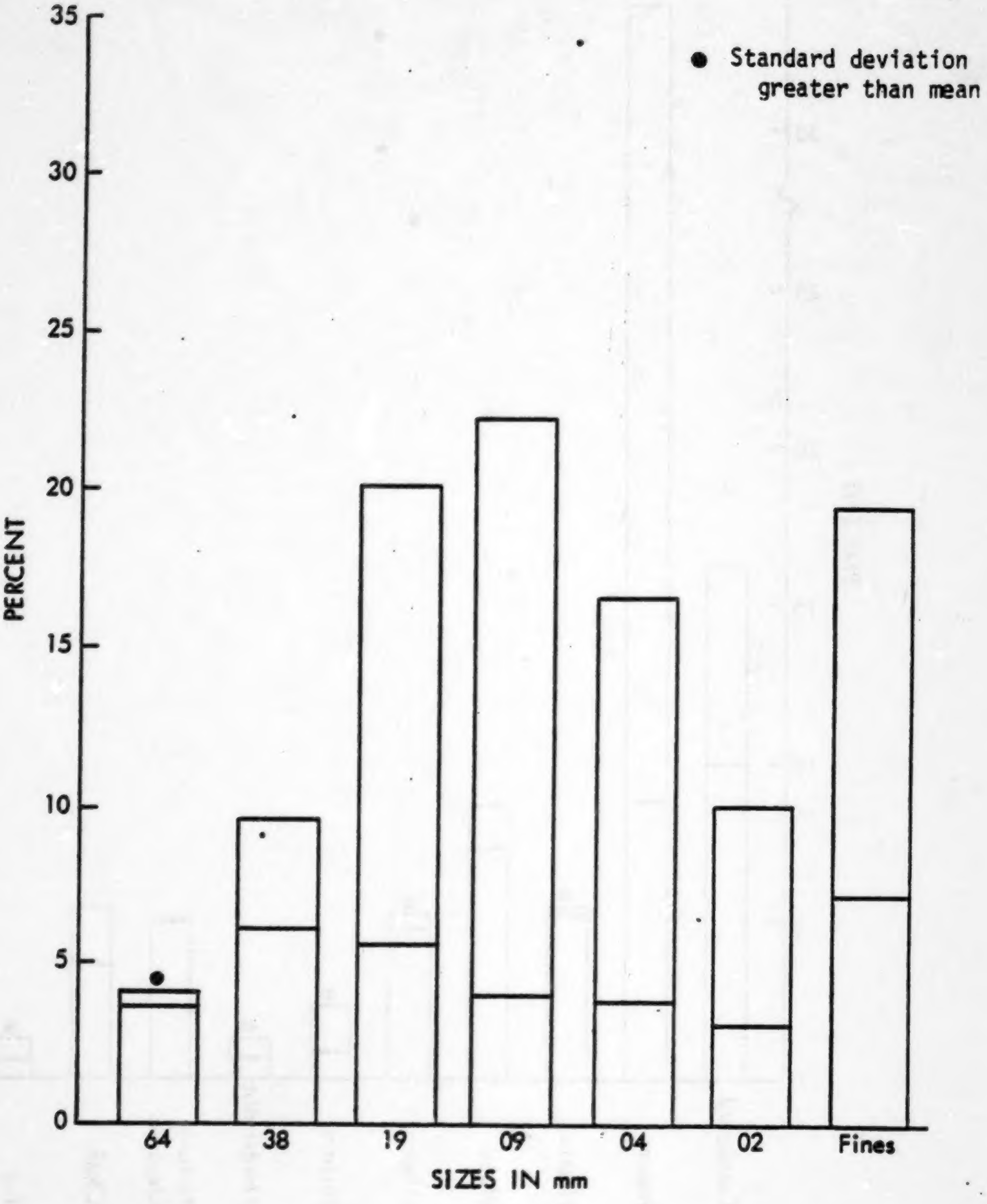

Figure 23. Secondary shredder discharge (C-6); size distribution.

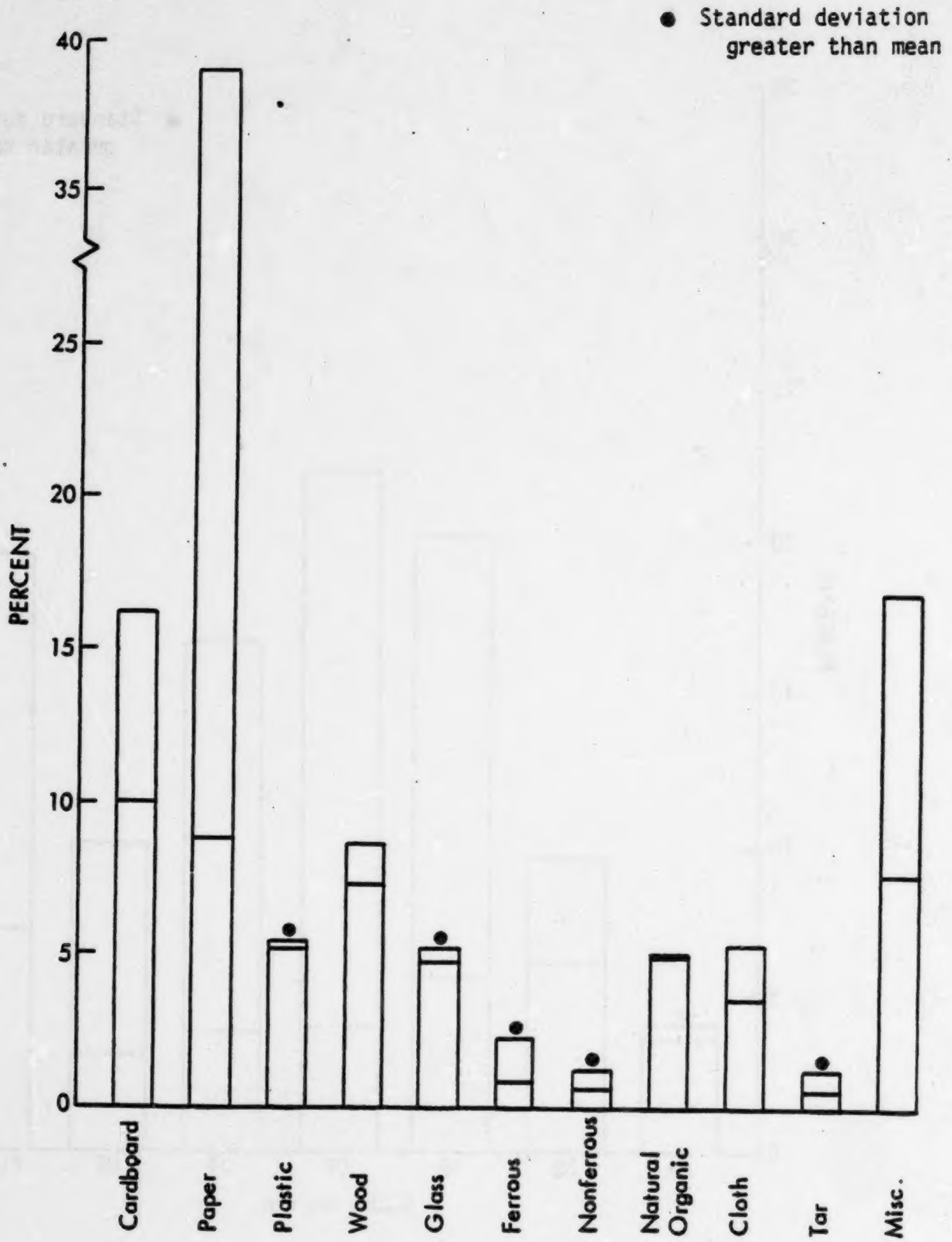

Figure 24. Secondary shredder discharge (C-6); composition.

Analytical laboratory analysis indicate an increase in as-received heating value from 11,600 to 12,300 kJ/kg with moisture reduction from 25 to 23%. The ash fraction and its elemental analysis are unchanged as shown in Figure 25. This material is the input to the ADS system.

AIR DENSITY SEPARATION SYSTEM

The ADS system consists of a surge bin, flight conveyor, vibrating screen conveyor, rotary air lock feeder, pneumatic separation chamber, cyclone separator, and a twin screw conveyor. Material samples were taken at the inlet to the surge bin (material discharged from the second shredder) at the inlet to the RDF storage bin (light fraction) and at the heavy fraction (C-7) conveyor.

System Input

The ADS system input is discussed above in the Second Shredder Discharge subsection. The major constituent of the input material is paper at 38% with cardboard as the second greatest at 16%.

RDF Output Fraction

The light fraction of RDF has a bulk density of 100 kg/m^3 and a sizing distribution which peaks at the fraction smaller than 2 mm (24% in this size range). The next greatest size range is in the 9 to 19 mm range with 20% of the material falling in this range as shown in Figure 26.

Composition of the RDF, Figure 27, shows that the paper fraction is the largest constituent at 38% with the miscellaneous nonclassifiable category second greatest at 21%.

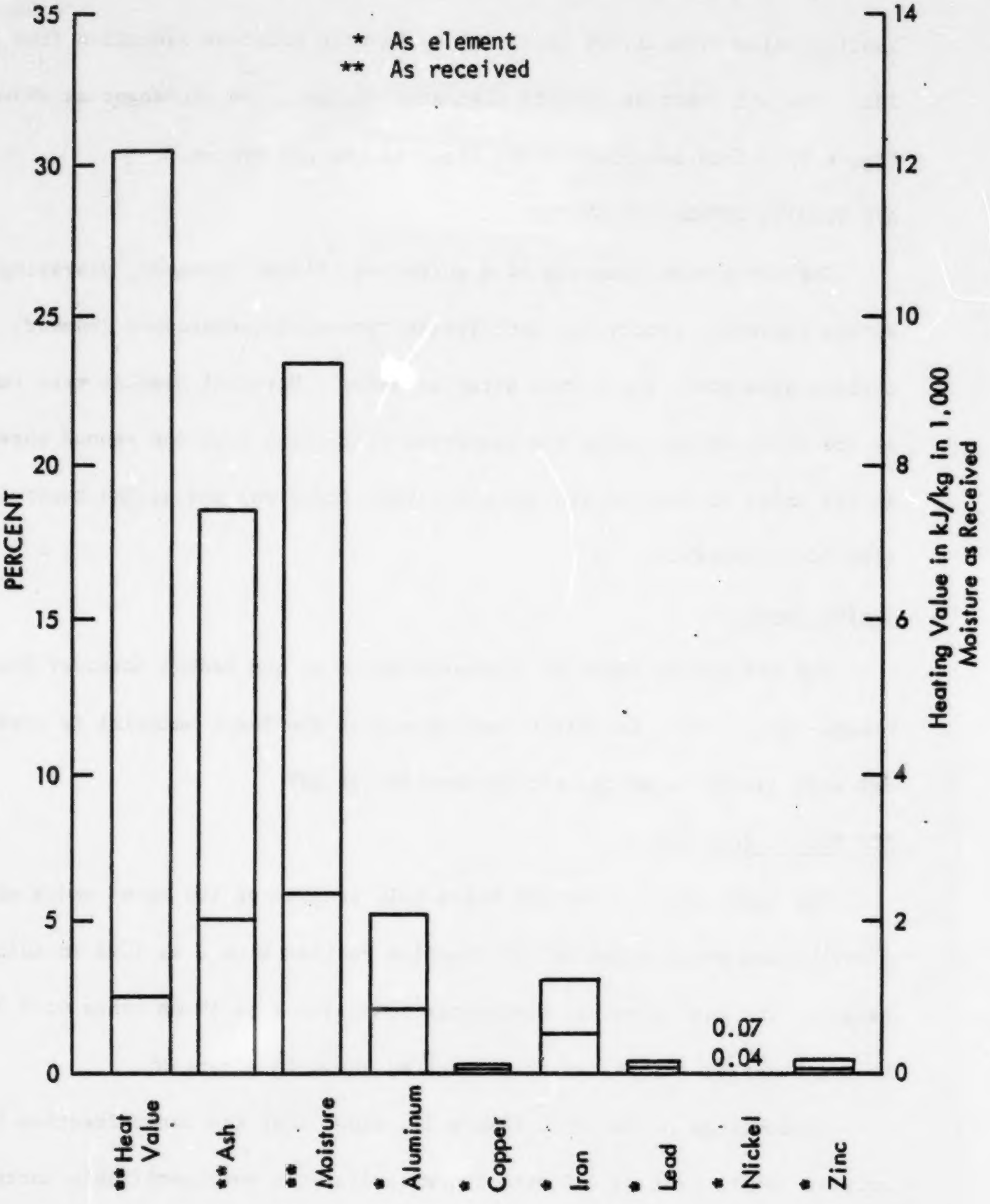

Figure 25. Secondary shredder discharge (C-6); laboratory analysis.

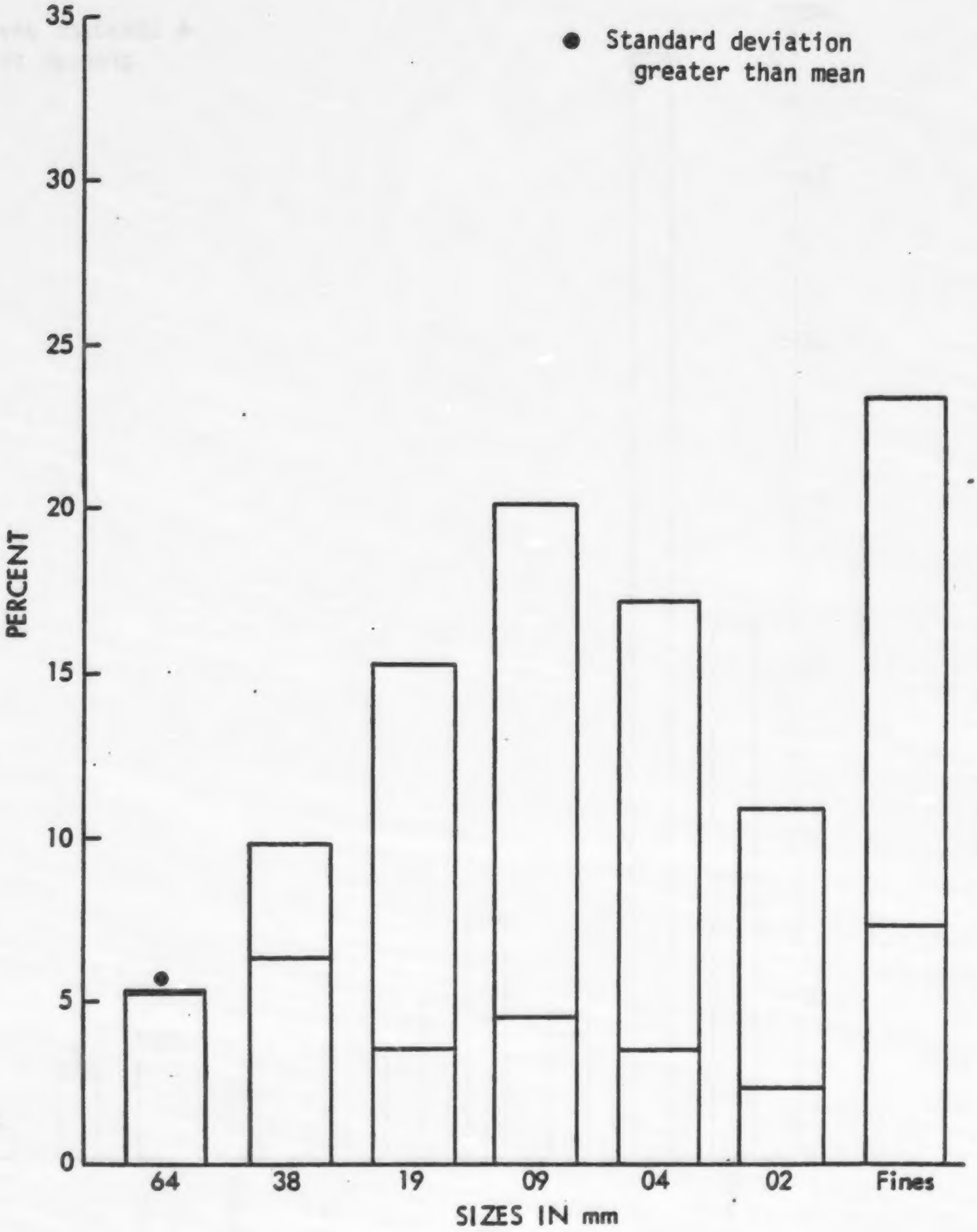

Figure 26. RDF; size distribution.

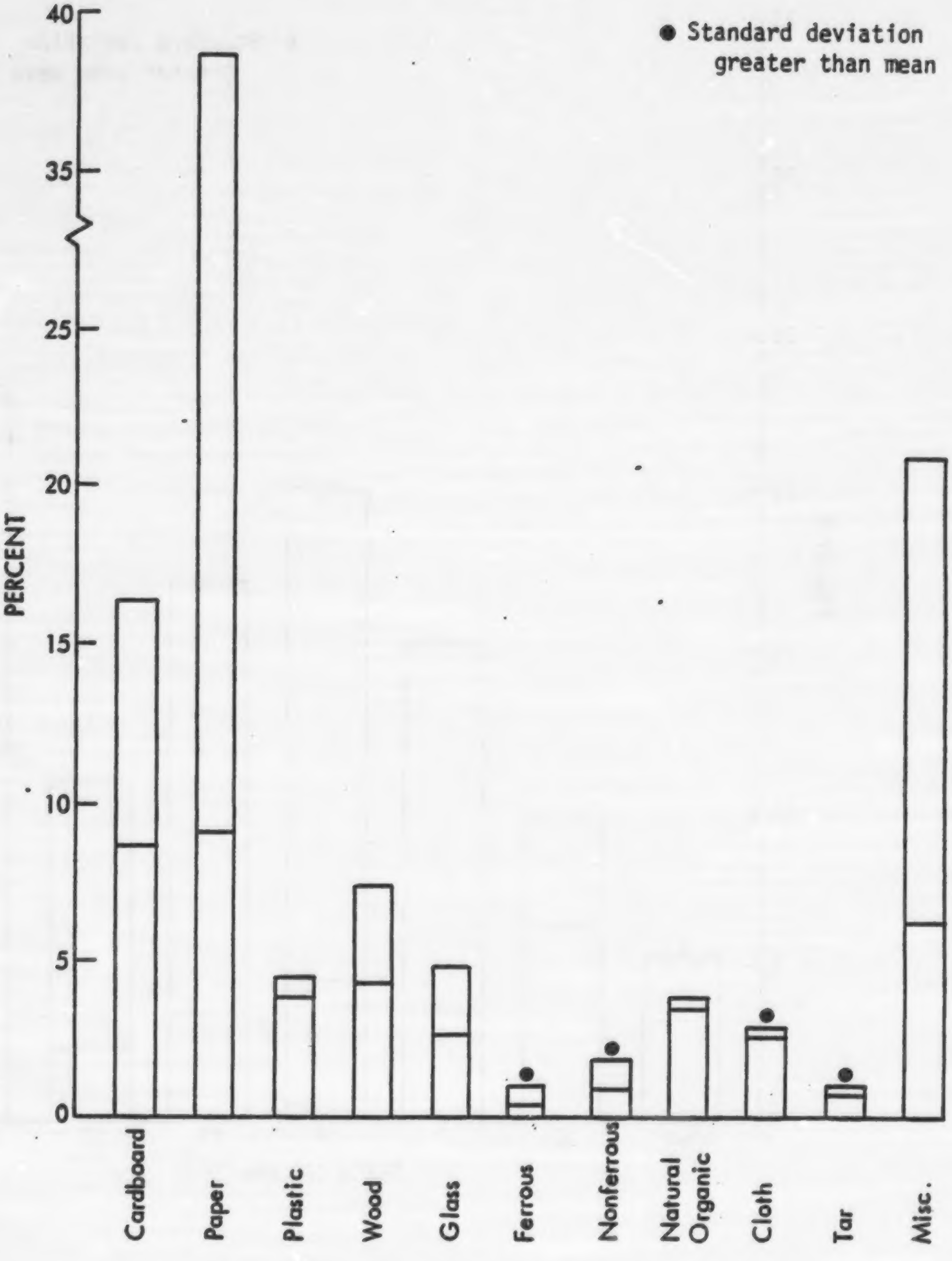

Figure 27. RDF; composition.

The cardboard fraction is 17%, with wood at 7%; all other constituents are 5% or less. Note that the glass fraction is 5%; this material is felt to be a major contribution to wear in the RDF storage/retrieval system. Ferrous and nonferrous metals are relatively small fractions by weight but subject to large variability as noted by standard deviations twice the mean values. This variability, as well as the form of the metals (wire, can lids, etc.), must be taken into account in usage of the RDF.

Figure 28 gives the analytical laboratory analysis results. It is seen that the heating value is 12,100 kJ/kg with a moisture level of 22% and an ash level of 18%; volatile matter (free carbons) are at 30% and fixed carbon at 28%. Elements of environmental concern including chlorine, sulfur, copper, lead, and zinc are less than 1/2% levels.

Heavy Fraction

The bulk density of the heavy fraction is found to be 450 kg/m^3; the sizing distribution is shown in Figure 29, where it is seen that the largest fraction (25%) of the material lies between 19 and 38 mm. The fine material makes up 15% of the material compared to 24% in the RDF; apparently, the fine material tends to fly as opposed to dropping out.

Composition of the heavy material is given in Figure 30, where it is seen that the miscellaneous category is the largest fraction at 25% followed by glass at 20%. Ferrous metals make up 16% and wood constitutes 13% of the heavies by weight; these materials are further processed through two stages of ferrous removal to extract the remaining ferrous as an output product.

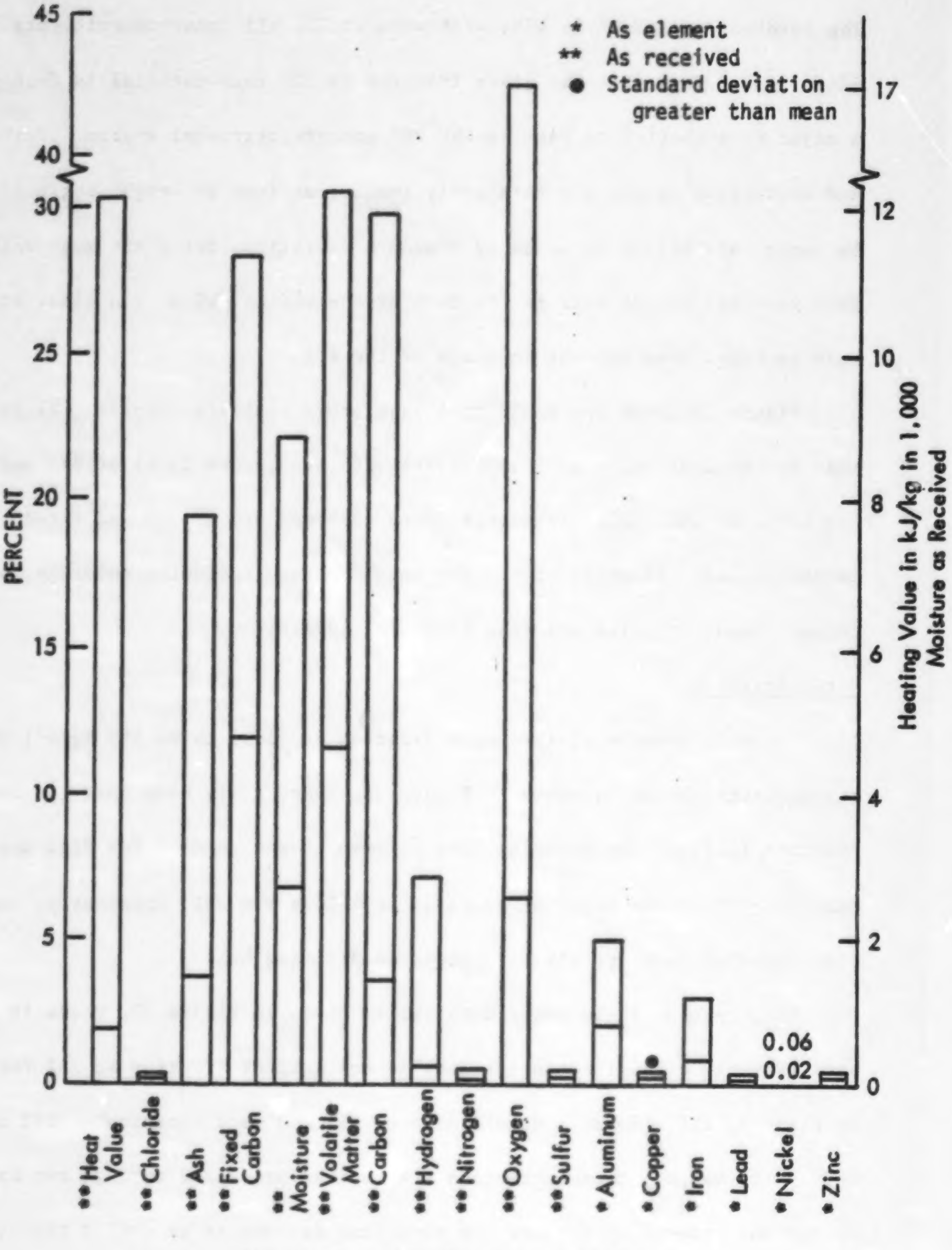

Figure 28. RDF; laboratory analysis.

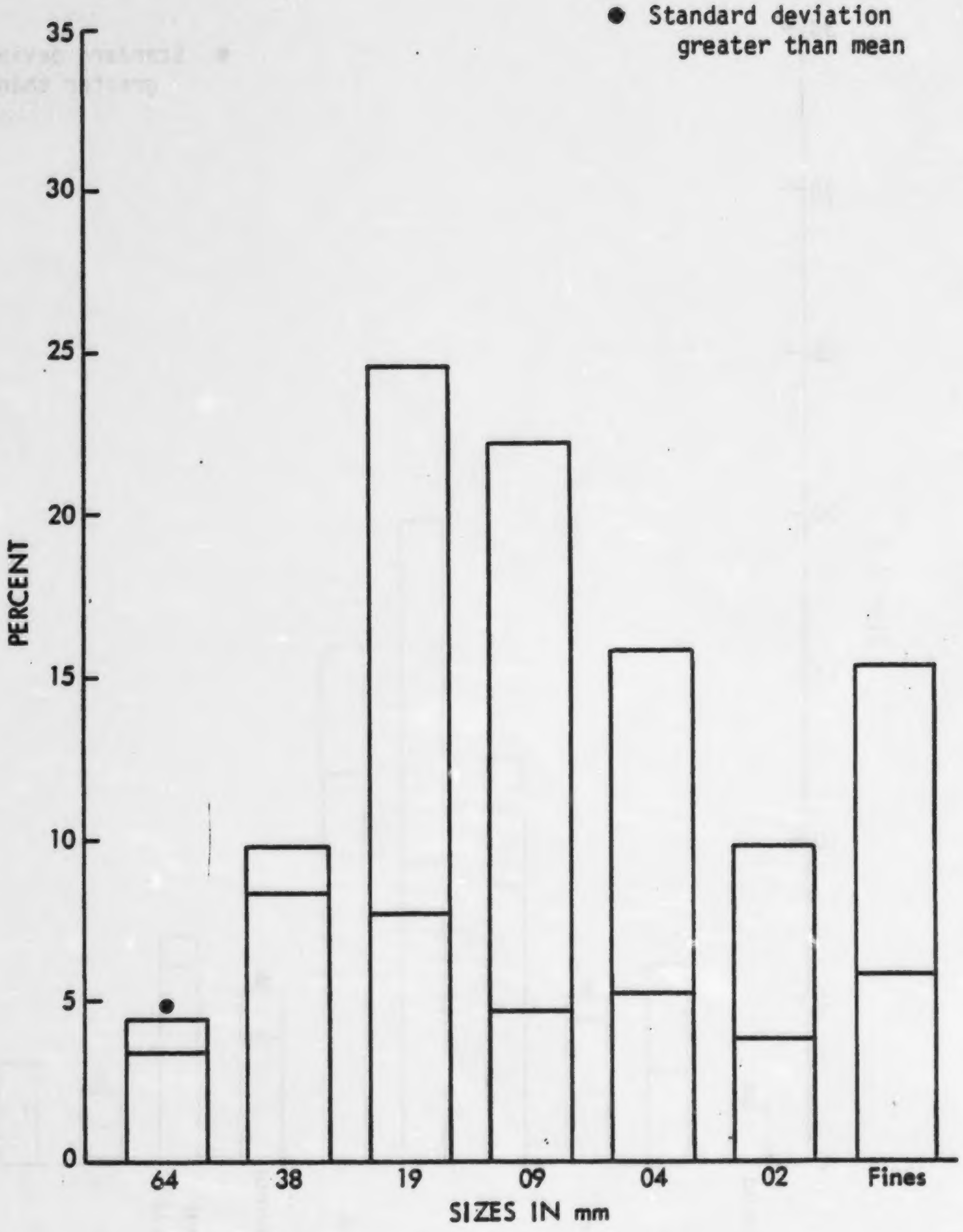

Figure 29. ADS heavies (C-7); size distribution.

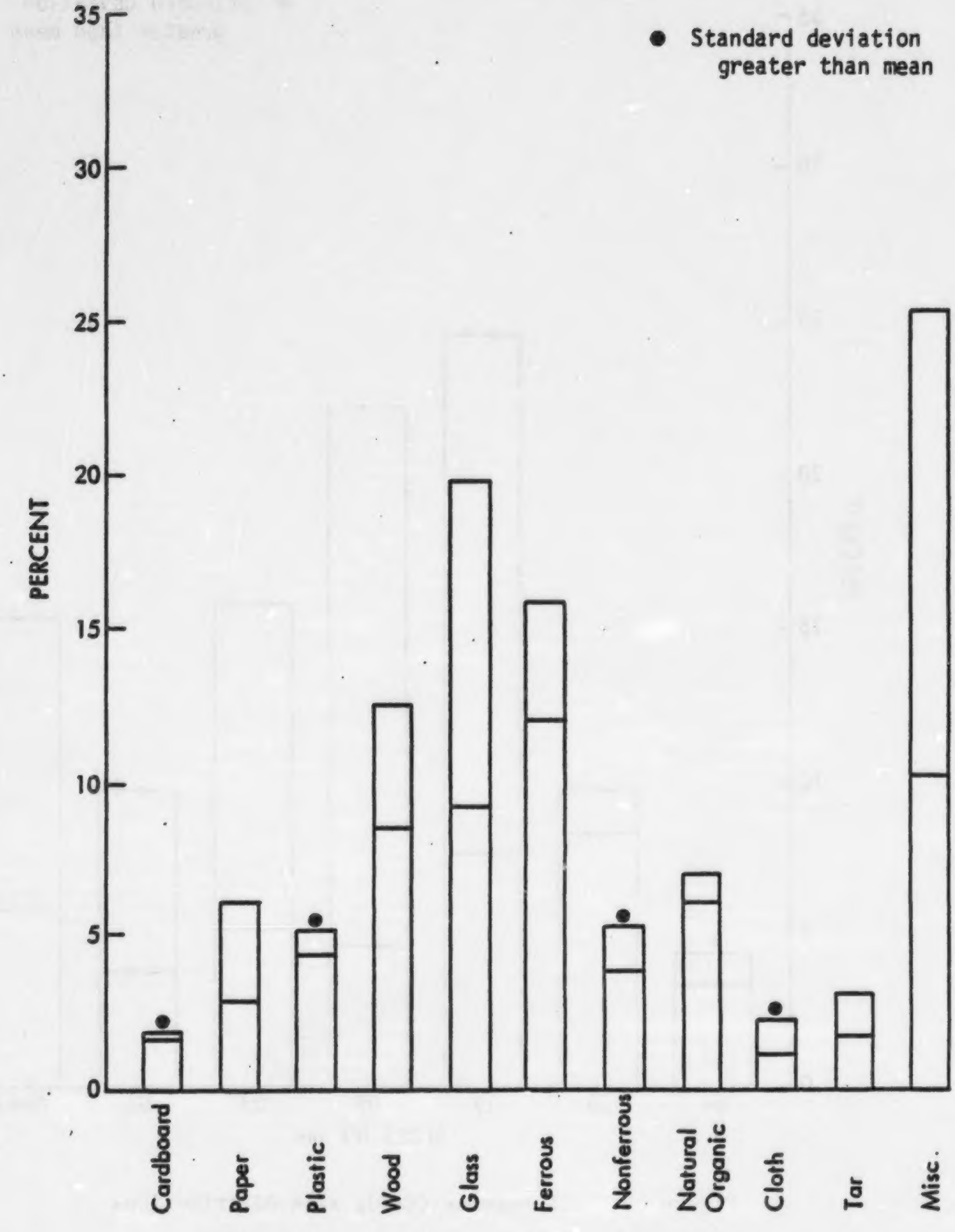

Figure 30. ADS heavies (C-7); composition.

The materials which remain after the final ferrous removal are the rejects and are taken to the landfill for disposal.

The analytical laboratory analysis is given in Figure 31 and shows the heating value of the heavies are 10,000 kJ/kg with an ash content of 39% and a moisture level of 16%. It is seen that the heavies can be considered a low grade fuel; the potential exists for their use in a mass burn heat recovery incinerator.

FERROUS METALS SEPARATION

Ferrous metals are removed from the process stream at three separate locations in the system. The first occurs immediately after shredded refuse leaves the first stage shredder by use of the Dings magnet belt (magnetic separator No. 1). Ferrous metal removed by the Dings is deposited on C-10 for further cleanup by passage under a magnetic tail pulley on C-12. This cleaned ferrous is deposited on C-13. The debris from the cleanup falls on C-11 where it is returned back onto the second stage shredder feed (C-3).

The second ferrous removal is performed on the ADS rejects on C-7 belt as it passes under a magnetic tail pulley on C-7A (magnetic separator No. 2). This removed ferrous is ultimately delivered to C-13. The final (or third ferrous removal stage) is achieved by use of a magnetic head pulley on C-14. The rejects leaving C-14 pass on to C-15 for transfer to the rejects storage bin.

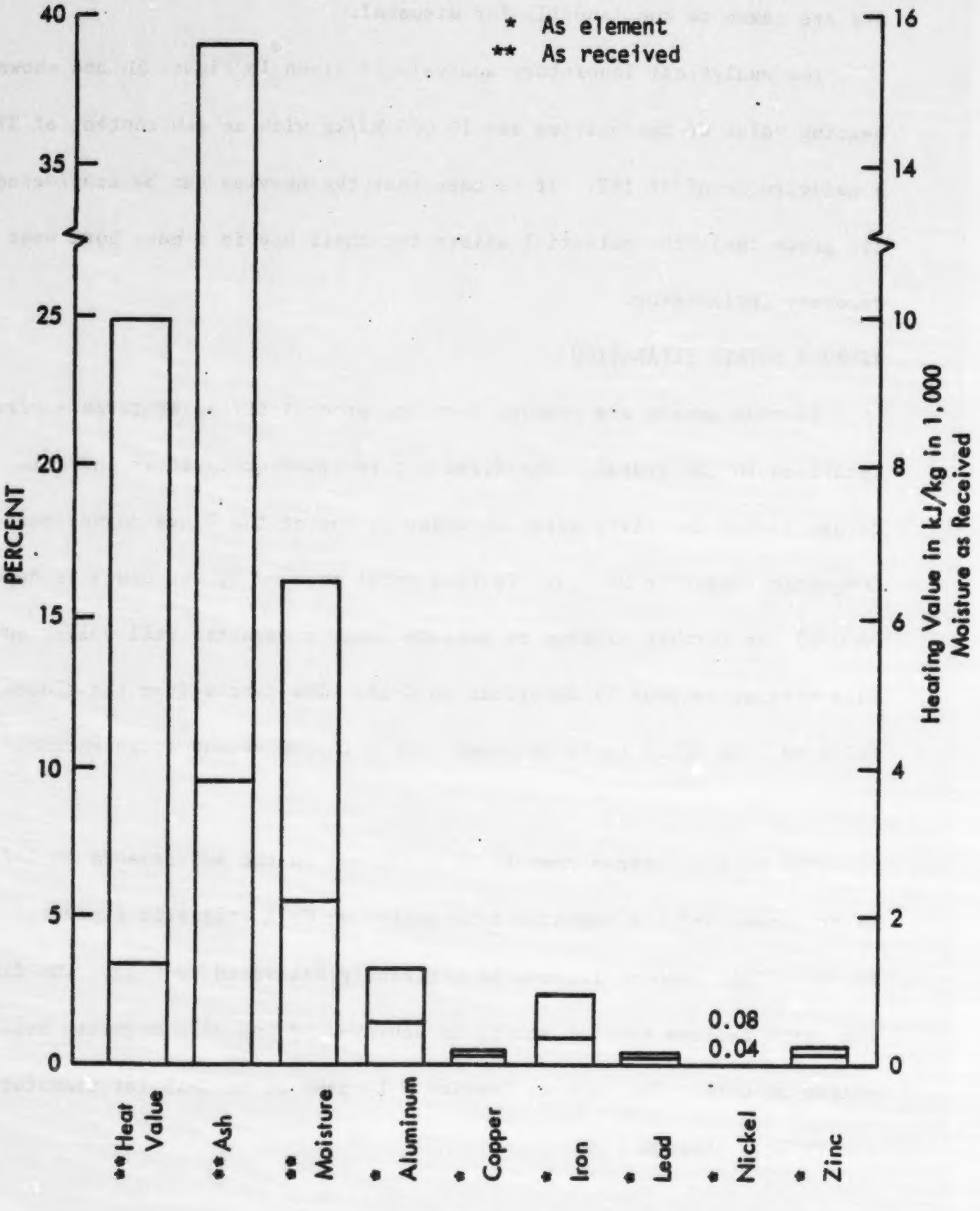

Figure 31. ADS heavies (C-7); laboratory analysis.

The ferrous product from the Dings magnet system is found to have a bulk density of 270 kg/m^3; the sizing distribution is shown in Figure 32, where it is seen that the largest portion of the sizing fraction is the largest size (64 mm) and constitutes 51% of the material. Composition of this material is given in Figure 33, where it is seen that the ferrous content is 98%; the next largest constituent is paper at 1%. Note that the paper and all other nonferrous materials exhibit large variability. The material returned to the second shredder which is not picked up by the tail pulley magnet on conveyor C-12 (magnetic separator No. 3) has a bulk density of 60 kg/m^3; its sizing distribution is shown in Figure 34. Note that it is relatively large material, as 36% is larger than 64 mm. The composition of this material is shown in Figure 35, where it is seen that the largest fraction of this rejected material is ferrous (37%) followed by paper at 33%. The reason for the relatively large amount of ferrous material is partially due to the inability of magnetic separator No. 3 to pick up relatively large ferrous pieces such as bolts, shafts, etc. Another factor may be the behavior when any ferrous metal in the shredder discharge is buried under a layer of shredded refuse.

The ferrous material removed from the air density separator heavies stream by the tail pulley magnet (magnetic separator No. 2) on conveyor C-7A is found to have a bulk density of 550 kg/m^3. The sizing distribution is given in Figure 36, where it is seen that most of the material lies in the 38 to 64 mm range (37%) and the 19 to 38 mm range (36%).

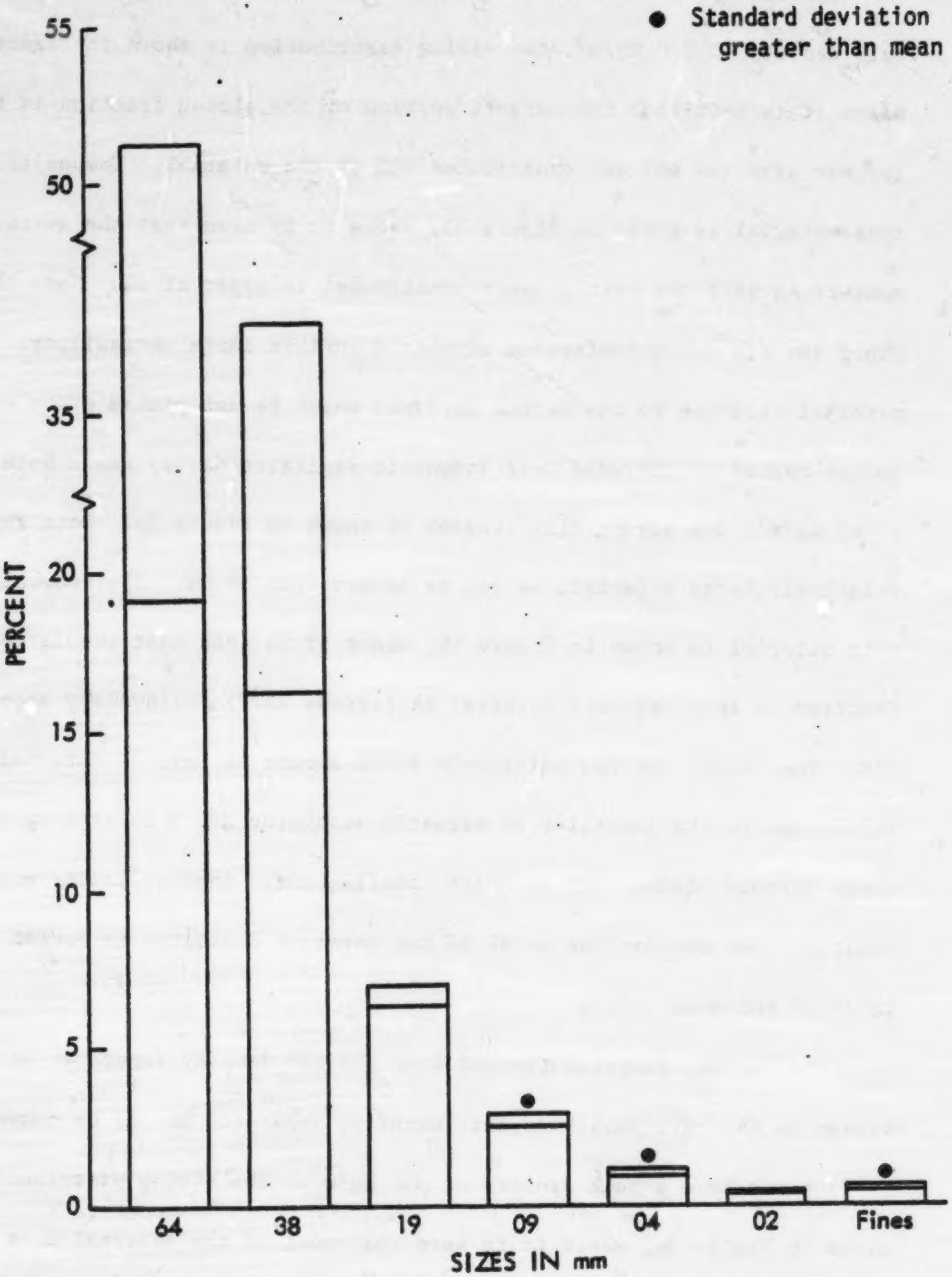

Figure 32. Dings magnet ferrous removal (C-12); size distribution.

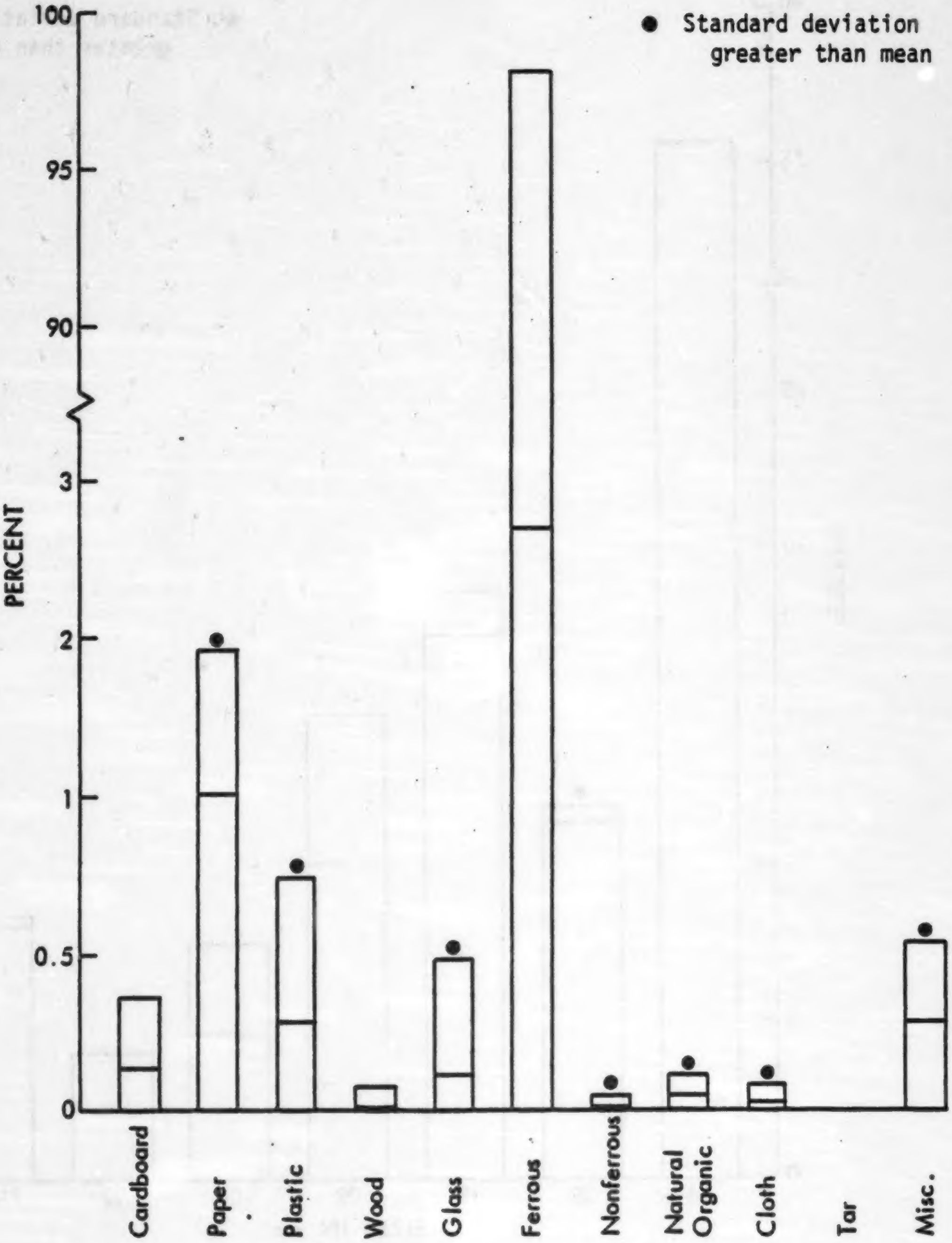

Figure 33. Dings magnet ferrous removal (C-12); composition.

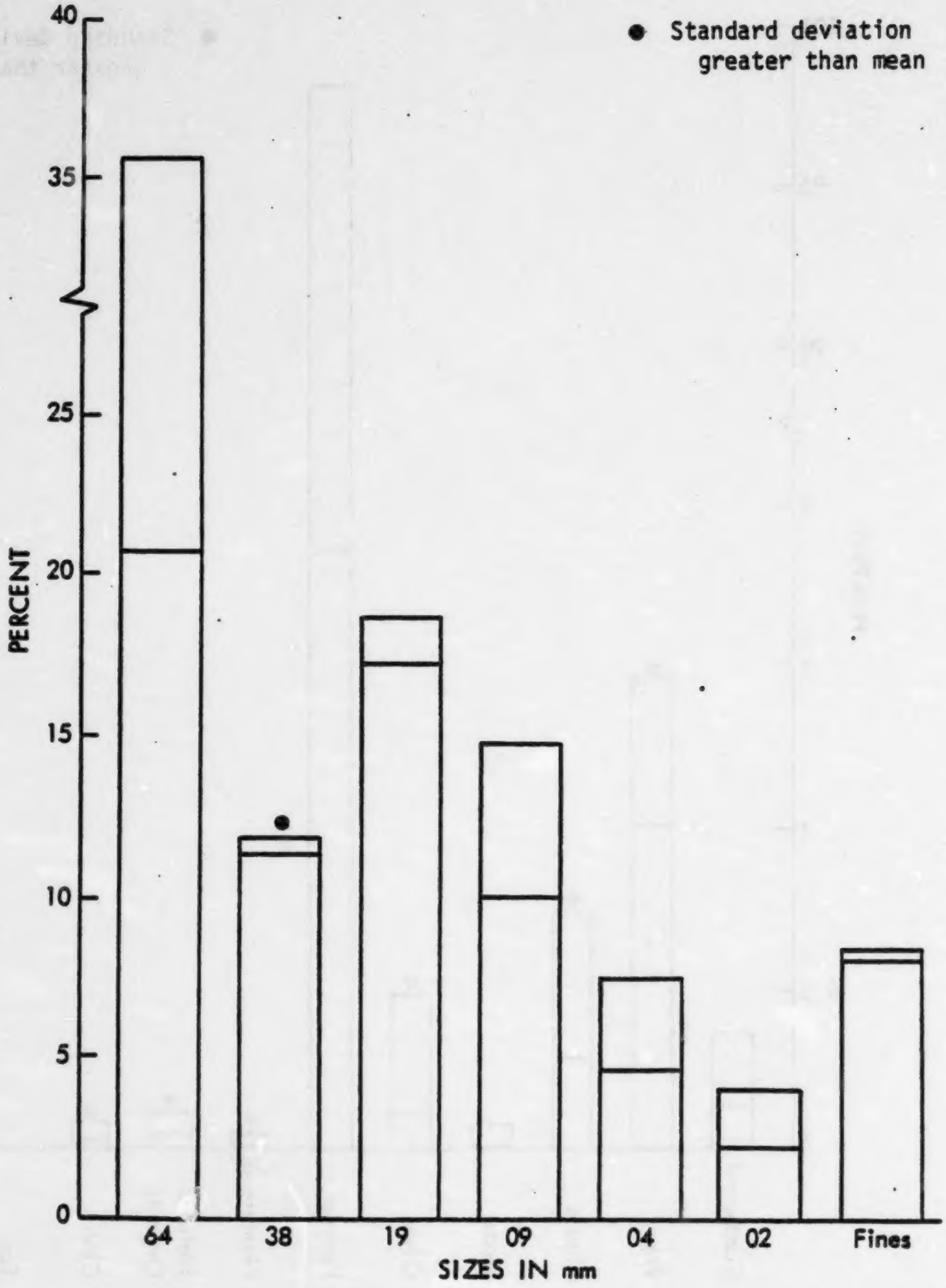

Figure 34. Dings magnet cleanup return (C-11); size distribution.

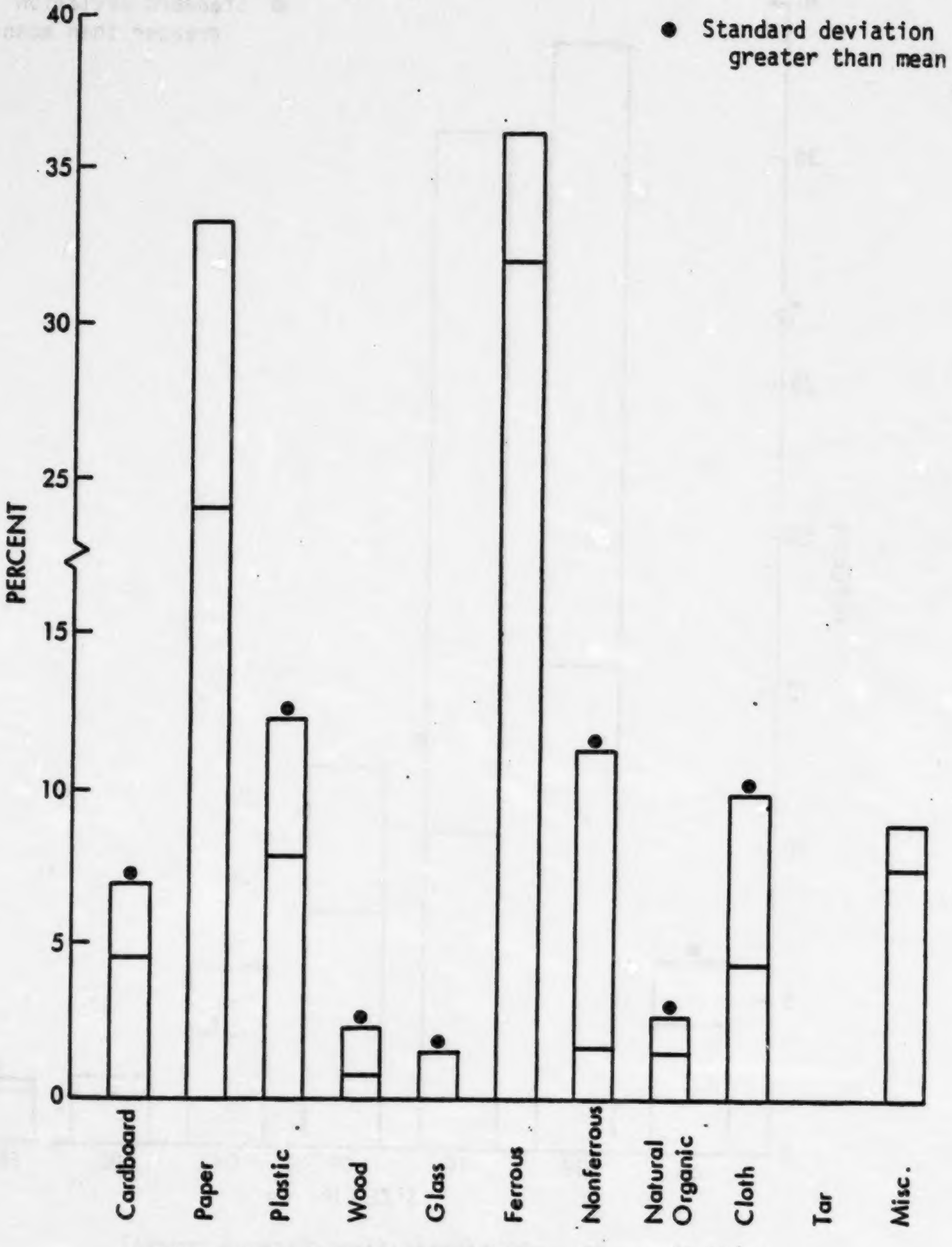

Figure 35. Dings magnet cleanup return (C-11); composition.

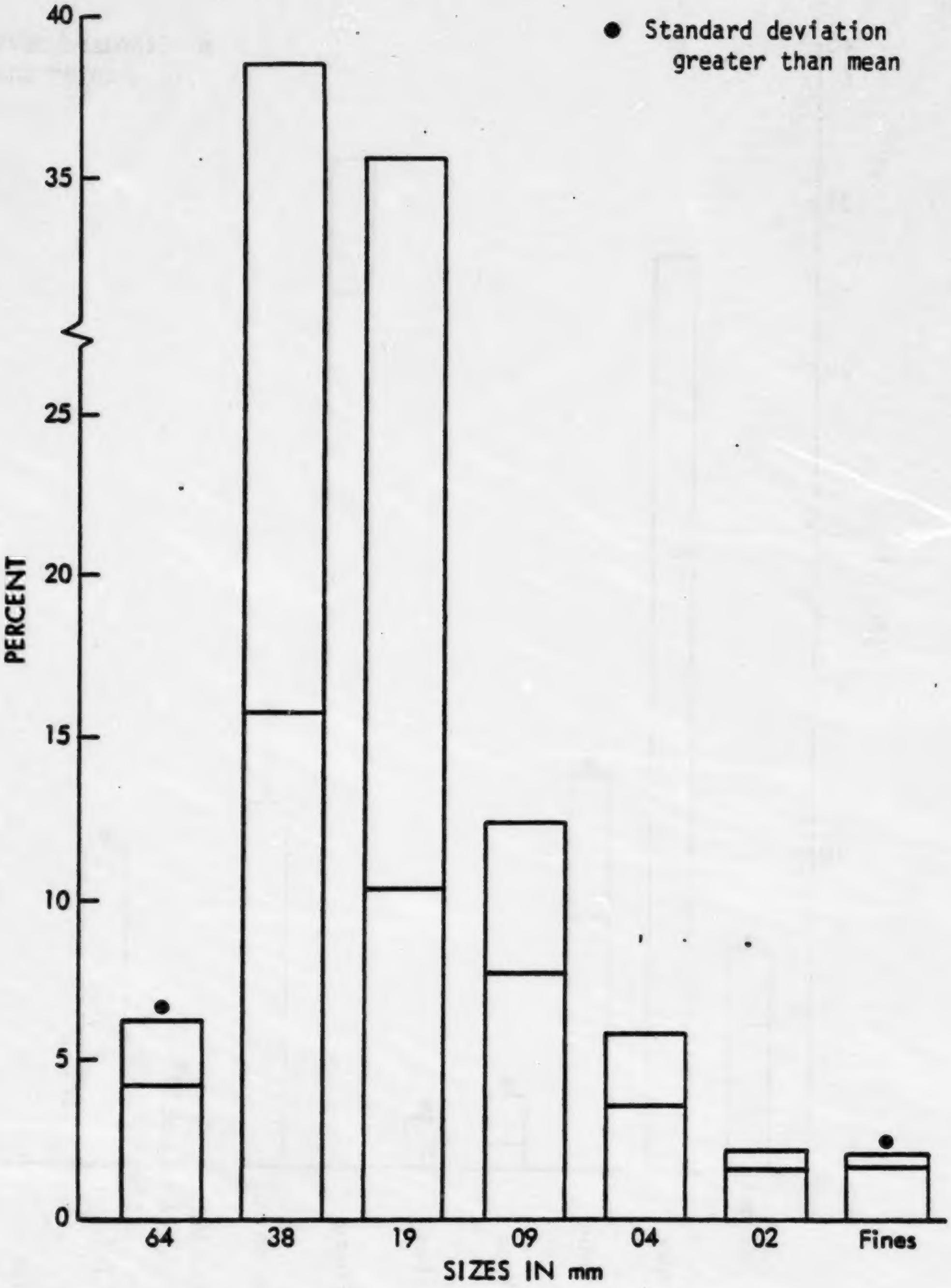

Figure 36. ADS heavies first ferrous removal (C-7A); size distribution.

Composition of this material is given in Figure 37, where it is seen that 97% is ferrous.

The second ferrous removal from the ADS heavies is removed by a head pulley magnet (magnetic separator No. 4) or conveyor C-14 and deposited into the chute to conveyor C-13. The bulk density of this material is 640 kg/m^3, and its size distribution is shown in Figure 38; the size peaks in the 9 through 38 mm region (55% of the material). Characteristics of the material are given in Figure 39; the major constituent is ferrous, but the fraction is only 68% which is relatively impure compared to other ferrous streams. The nonclassifiable category is 10%, and paper is almost 5% of this fraction.

The composite ferrous product is carried out of the system on conveyor C-13; its bulk density is found to be 300 kg/m^3. The size distribution is given in Figure 40 with 77% of the material larger than 38 mm. Composition of the output ferrous stream is given in Figure 41, where it is seen that the ferrous component is 96% and all contaminants in this stream are less than 1% but with large variability.

REJECTS SYSTEM

Rejects from the process originate from the ADS heavies stream; two stages of ferrous removal are used to extract ferrous metal from this stream. Reject material after the first stage of ferrous removal are found to have a bulk density of 410 kg/m^3; the sizing distribution of the material is shown in Figure 42. The greatest fraction of the material (25%) is in the 19 to 38 mm size range with 23% in the 9 to 19 mm size range.

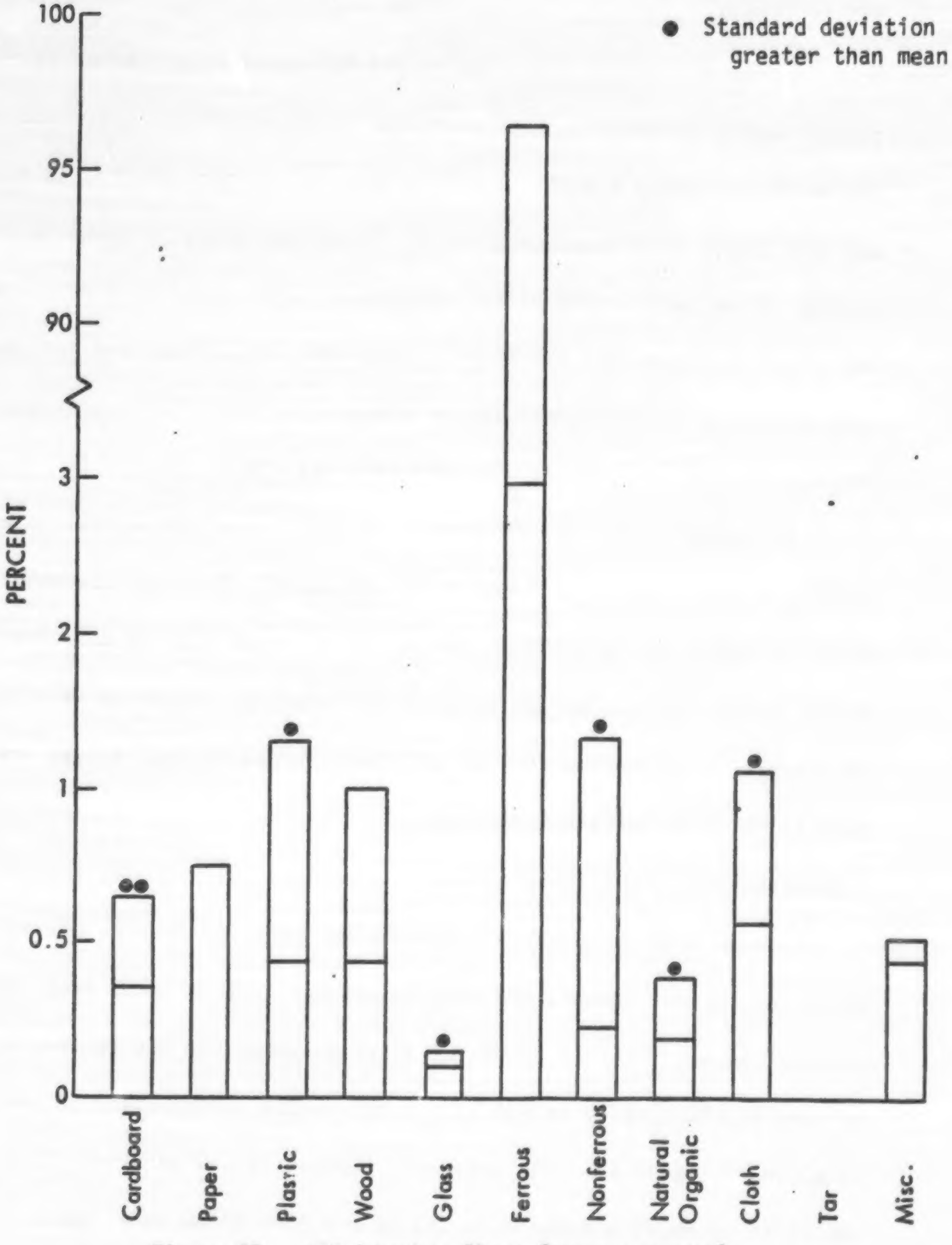

Figure 37. ADS heavies first ferrous removal (C-7A); composition.

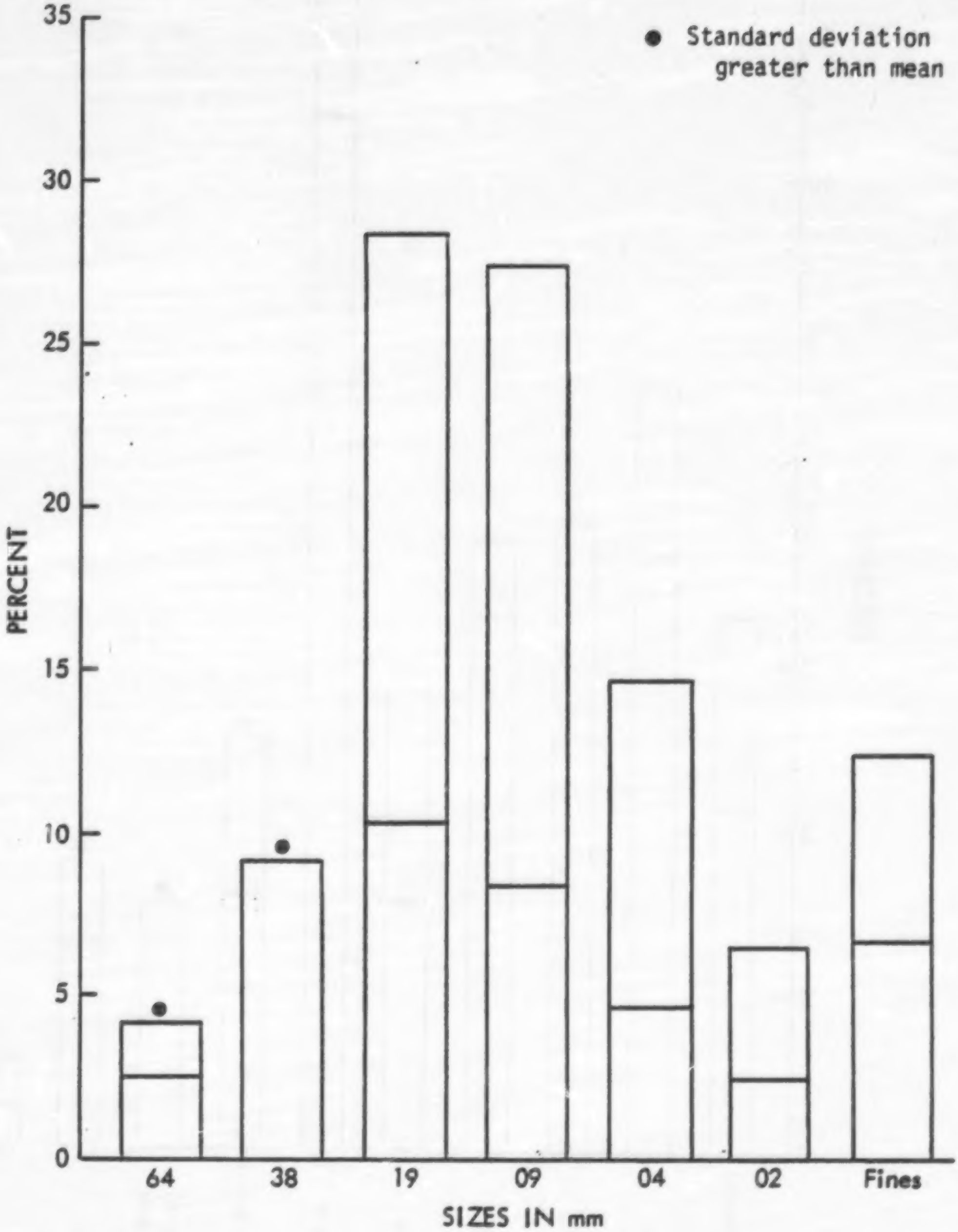

Figure 38. ADS heavies second ferrous removal (C-14 chute); size distribution.

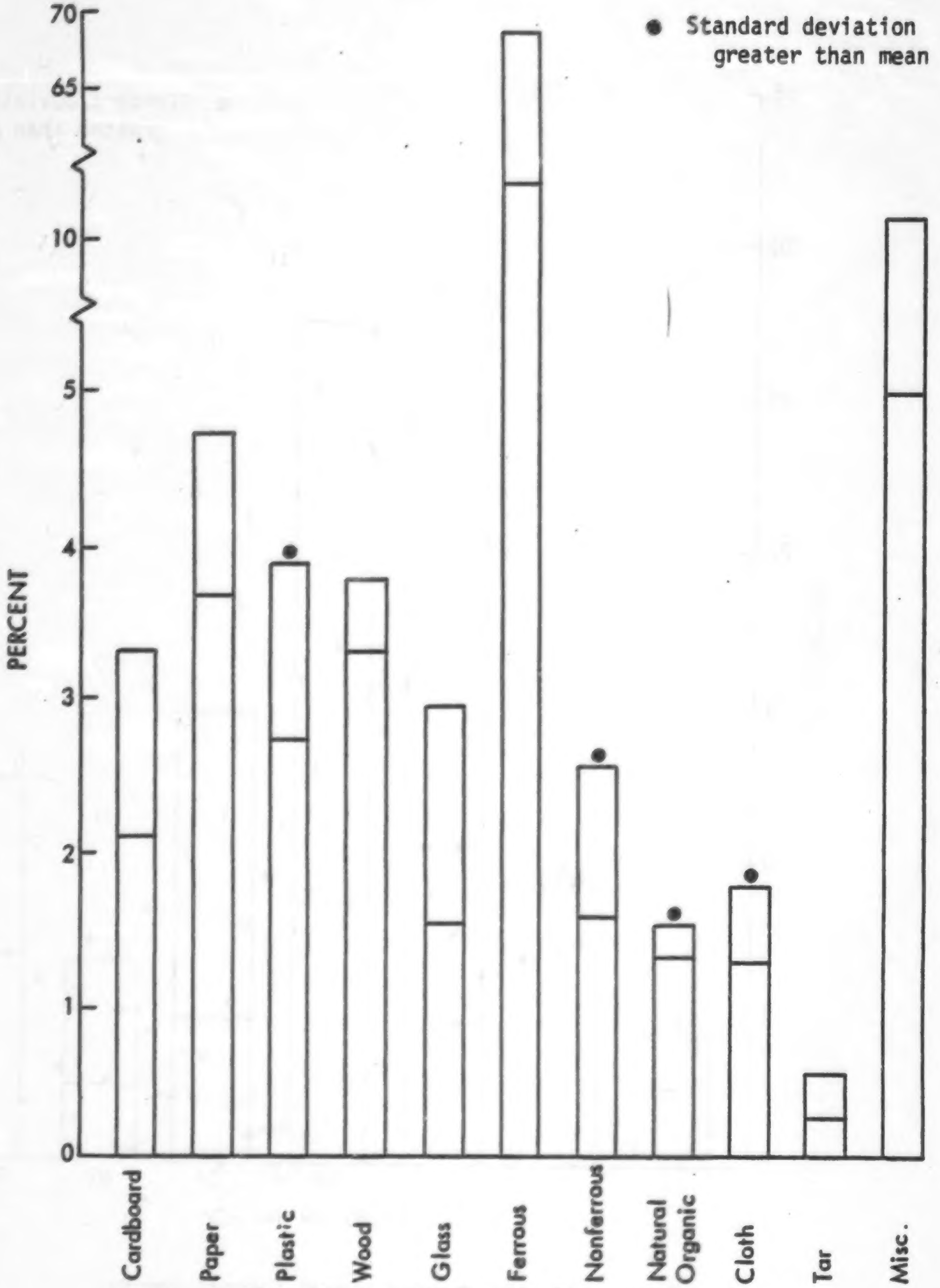

Figure 39. ADS heavies second ferrous removal (C-14 chute); composition.

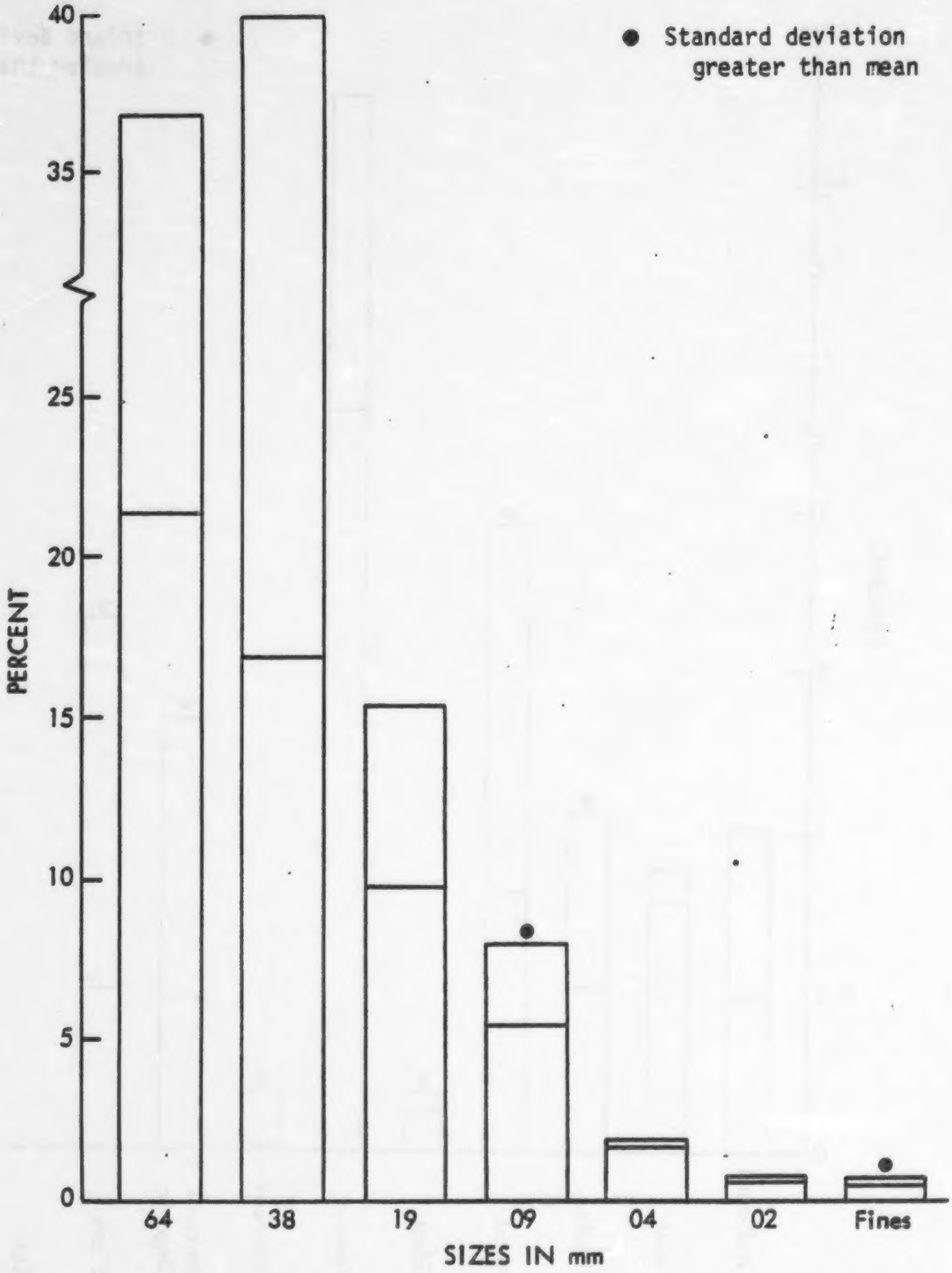

Figure 40. Total ferrous metal recovery (C-13); size distribution.

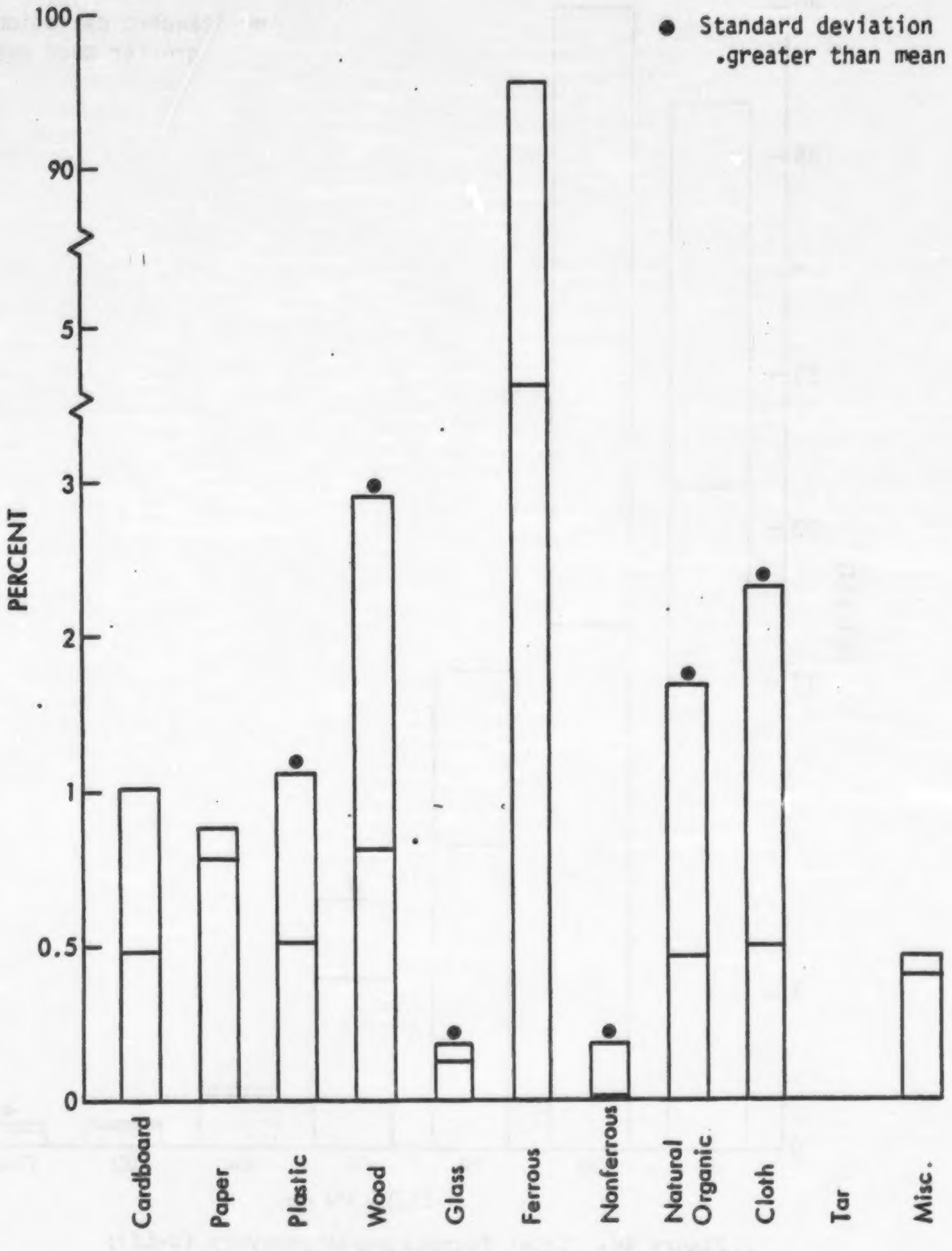

Figure 41. Total ferrous metal recovery (C-13); composition.

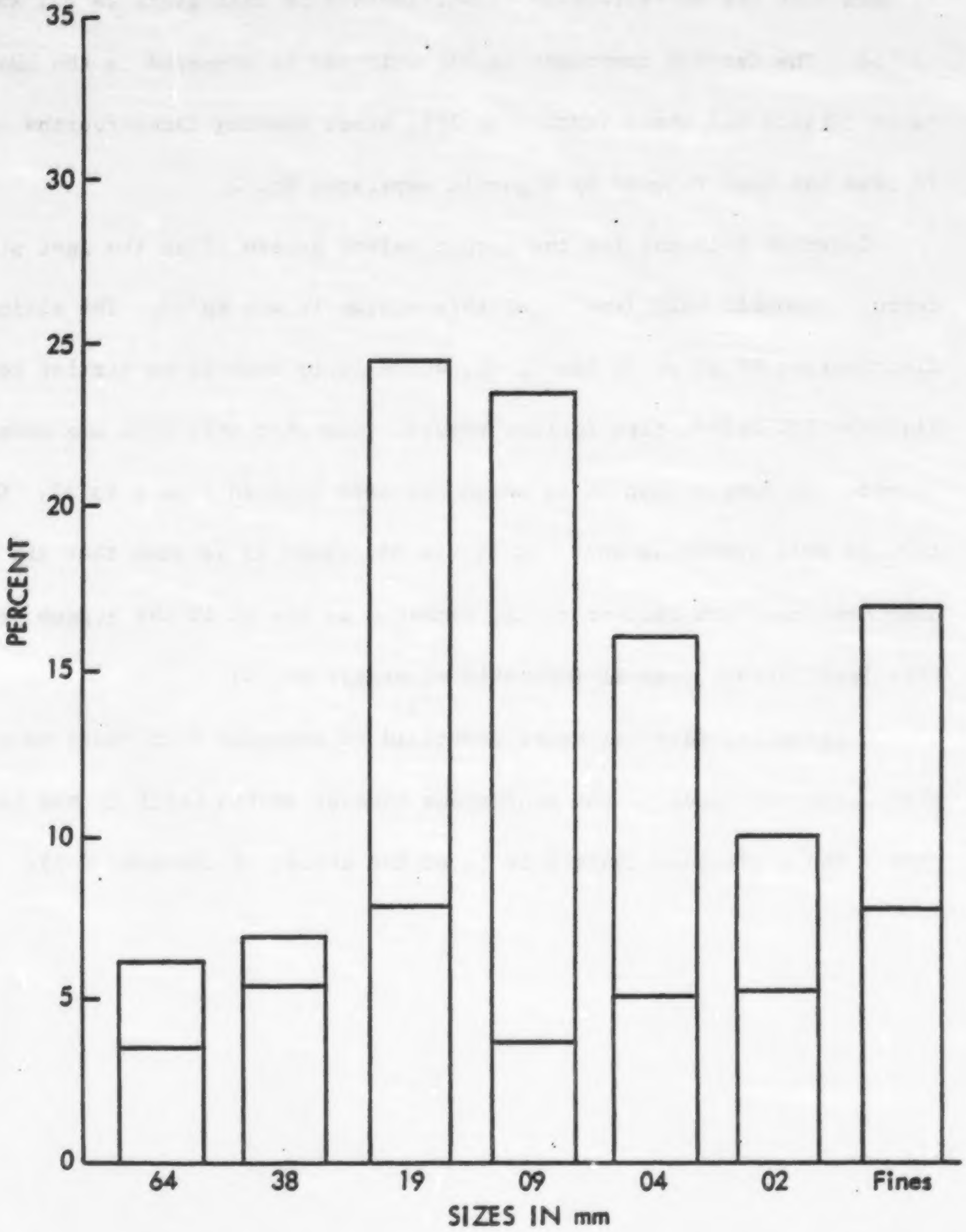

Figure 42. ADS heavies after first ferrous removal (E-1); size distribution.

The distribution of materials in this stream is shown in Figure 43, where it is seen that the miscellaneous classification is 28%; glass is 22% and wood is 15%. The ferrous component is 4%; this can be compared to the ADS rejects (Figure 30) where ferrous is 16%, hence showing three-fourths of the ferrous has been removed by magnetic separator No. 2.

Conveyor C-15 carries the output reject stream after the last stage of ferrous removal; bulk density of this stream is 400 kg/m^3. The sizing distribution is given in Figure 44, where it is seen to be similar to the distribution before this ferrous removal (elevator E-1) with the exception of material larger than 64 mm which has been reduced from 6 to 3%. Composition of this stream is shown in Figure 45, where it is seen that the ferrous component has been reduced to 1%, compared to the 4% in the stream prior to this last ferrous removal (magnetic separator No. 4).

Originally, material being deposited on conveyor C-15 could have been alternately diverted to the nonferrous removal system which is now inoperative. The nonferrous content is 6% of the stream at conveyor C-15.

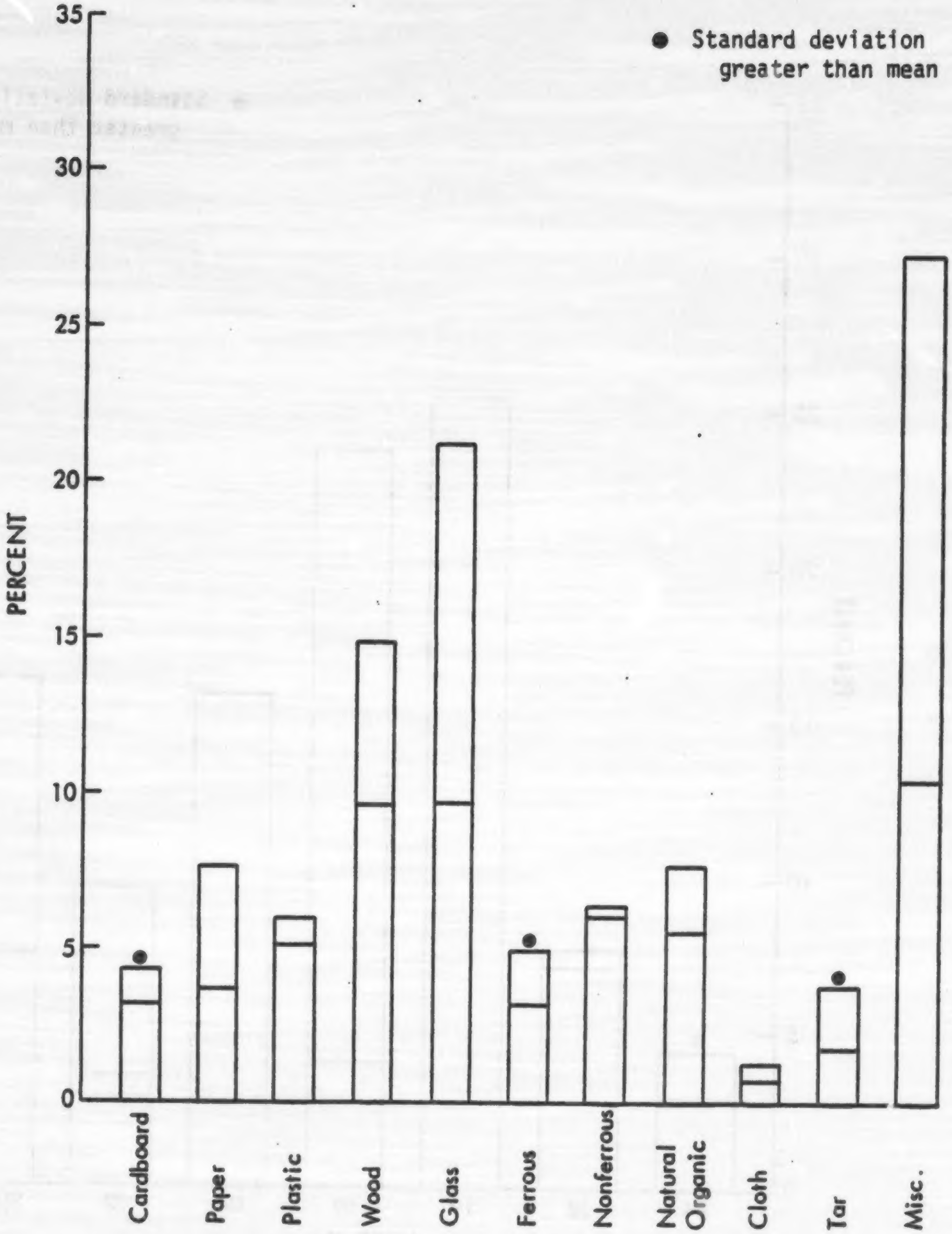

Figure 43. ADS heavies after first ferrous removal (E-1); composition.

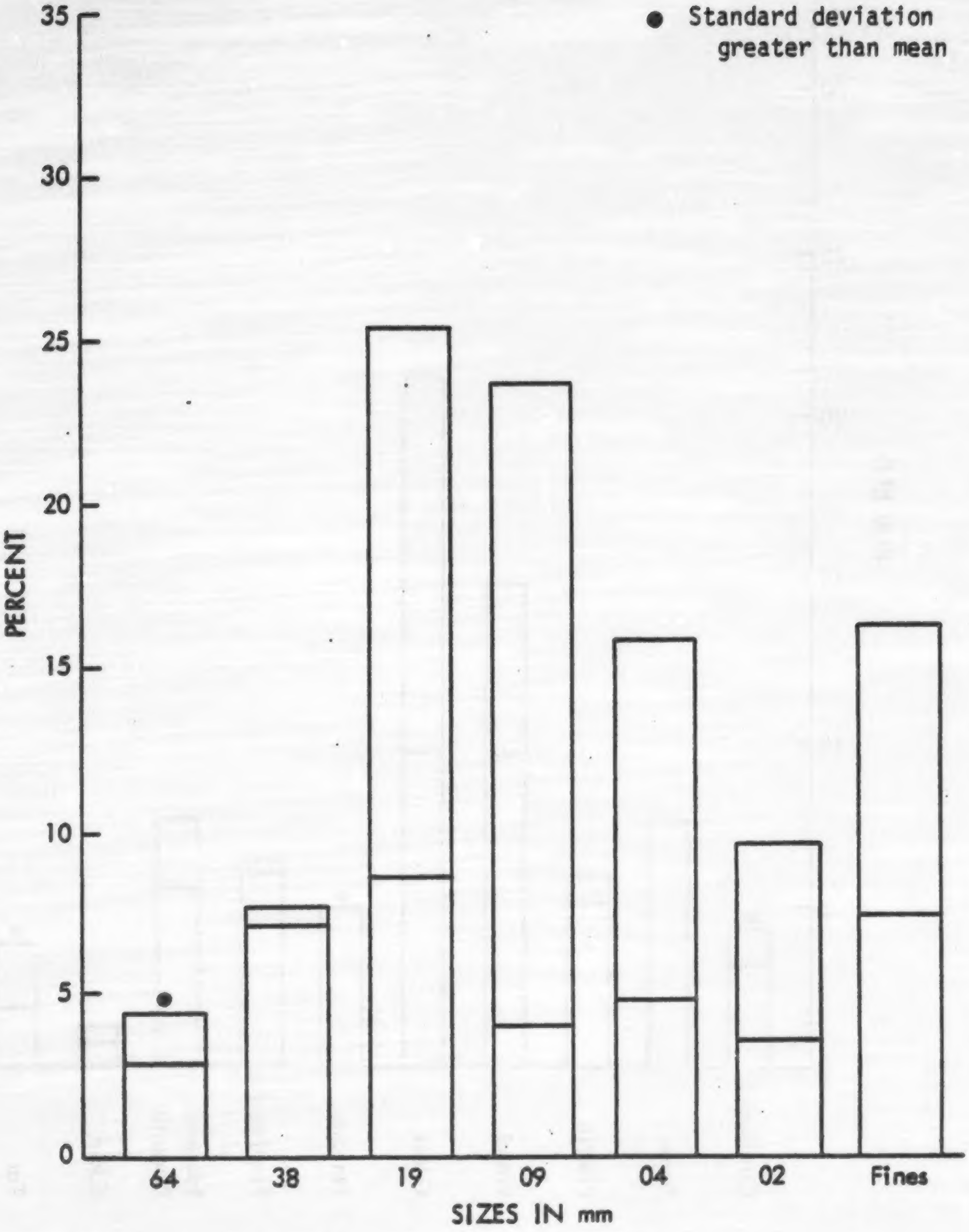

Figure 44. Rejects (C-15); size distribution.

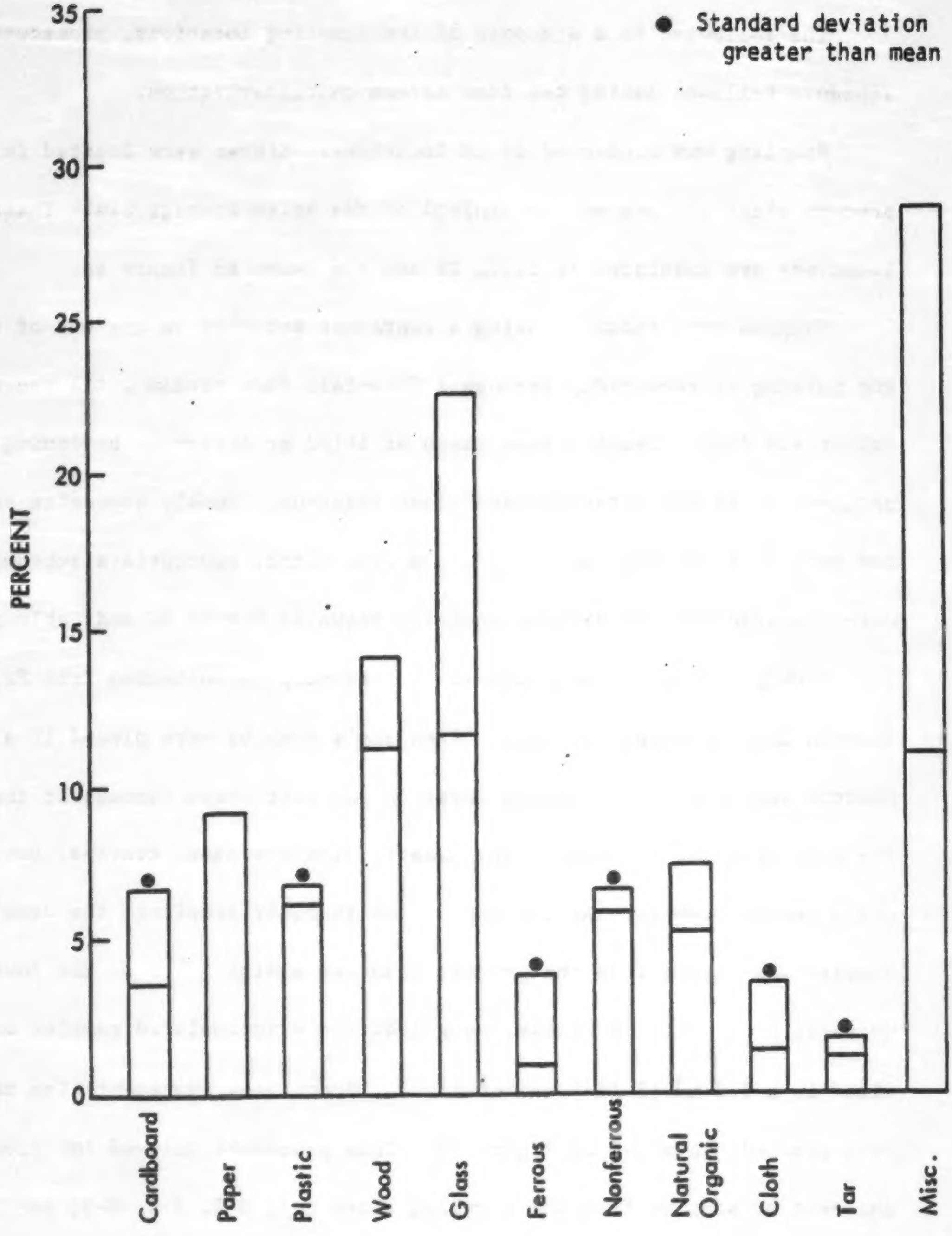

Figure 45. Rejects (C-15); composition.

GENERAL PROCEDURE

The following is a synopsis of the sampling locations, procedures, and schedule followed during the flow stream characterization.

Sampling was conducted at 12 locations. Eleven were located inside the process plant and one on top (inlet) of the Atlas storage bin. These locations are tabulated in Table 29 and are shown in Figure 46.

Samples were taken by using a container attached to the end of the rod and passing it repeatedly through a free-fall flow stream until the container was full. Samples were taken at 1-1/2 hr intervals beginning approximately 15 min after process plant start-up. Weekly composite samples for each location were generated, and from these, appropriate subsamples were.prepared for the various analyses shown in Figure 47 and Table 30.

Weekly composites were developed from samples collected from Friday through the following Thursday. Each day's samples were placed in a 3 mil plastic bag near each sampling location and left there throughout the day. The bags were tied securely, and labeled with the date, conveyor number, and daily sample numbers. At the end of the Thursday sampling, the week's samples were taken from the process plant to a mixing lab on the Iowa State University campus. On Friday, each location's accumulated samples were mixed in a 0.2 m^3 (6 ft^3) cement mixer. From this, representative samples were removed, as shown in Figure 46. This procedure allowed for prompt shipment of samples from the sampling sites S-1, S-2, S-8, S-9, and S-10 to Raltech Laboratories, at St. Louis, Missouri, for appropriate analysis.

TABLE 29. SCHEDULE OF PROCESSING PLANT FLOW STREAMS TO BE SAMPLED AND CURRENT STATUS

Sample I.D. No.	Sampling location conveyor No.	Description of flow stream	Samples being taken	Reason if not
		Plant input/output		
S-1	C-2	Raw refuse - 1st stage shredder discharge - Conveyor C-2 with Dings magnet de-energized	Yes	
S-2	RDF	ADS lights discharged into Atlas storage bin	Yes	
S-4	C-13	Total ferrous metal recovered - Belt Conveyor C-13	Yes	
S-5	E-5	Aluminum recovered - Bucket Elevator E-5	No	Almag inoperative
S-6	E-4	Other nonferrous metal recovered - Bucket Elevator E-4	No	Almag inoperative
S-7A	E-3	Sand and glass - Bucket Elevator E-3	No	Almag inoperative
S-7B	E-2	Nonferrous metal rejects - Bucket Elevator E-2	No	Almag inoperative
S-7C	C-14	Magnetic Separator No. 4 discharge - metal chute from MAG. Hd. Conveyor C-14	Yes[a]	
		Internal flow streams		
S-8	C-3	Second stage shredder feed - Conveyor C-2 discharge with Dings magnet energized	Yes	
S-9	C-6	Second stage shredder discharge (feed to ADS) - Belt Conveyor C-6	Yes	
S-10	C-7	ADS separation chute discharge (ADS heavies) - Belt Conveyor C-7	Yes	
S-11	C-15	Reject discharge to bin - Belt Conveyor C-15	Yes	
S-12	C-10	Magnetic Separator No. 1 discharge - Belt Conveyor C-10	No	Inaccessible (replaced by S-16)
S-13	C-7A	Magnetic Separator No. 2 discharge - Belt Conveyor C-7A	Yes	

(continued)

TABLE 29. (concluded)

Sample I.D. No.	Sampling location conveyor No.	Description of flow stream	Samples being taken	Reason if not
S-14	C-12	Magnetic Separator No. 3 discharge - Belt Conveyor C-12	Yes	
S-15	E-1	Magnetic Separator No. 4 feed - Bucket Elevator E-1	Yes	
S-16	C-11	New sampling location at C-11 to replace S12	Yes	

a/ Called "chute."

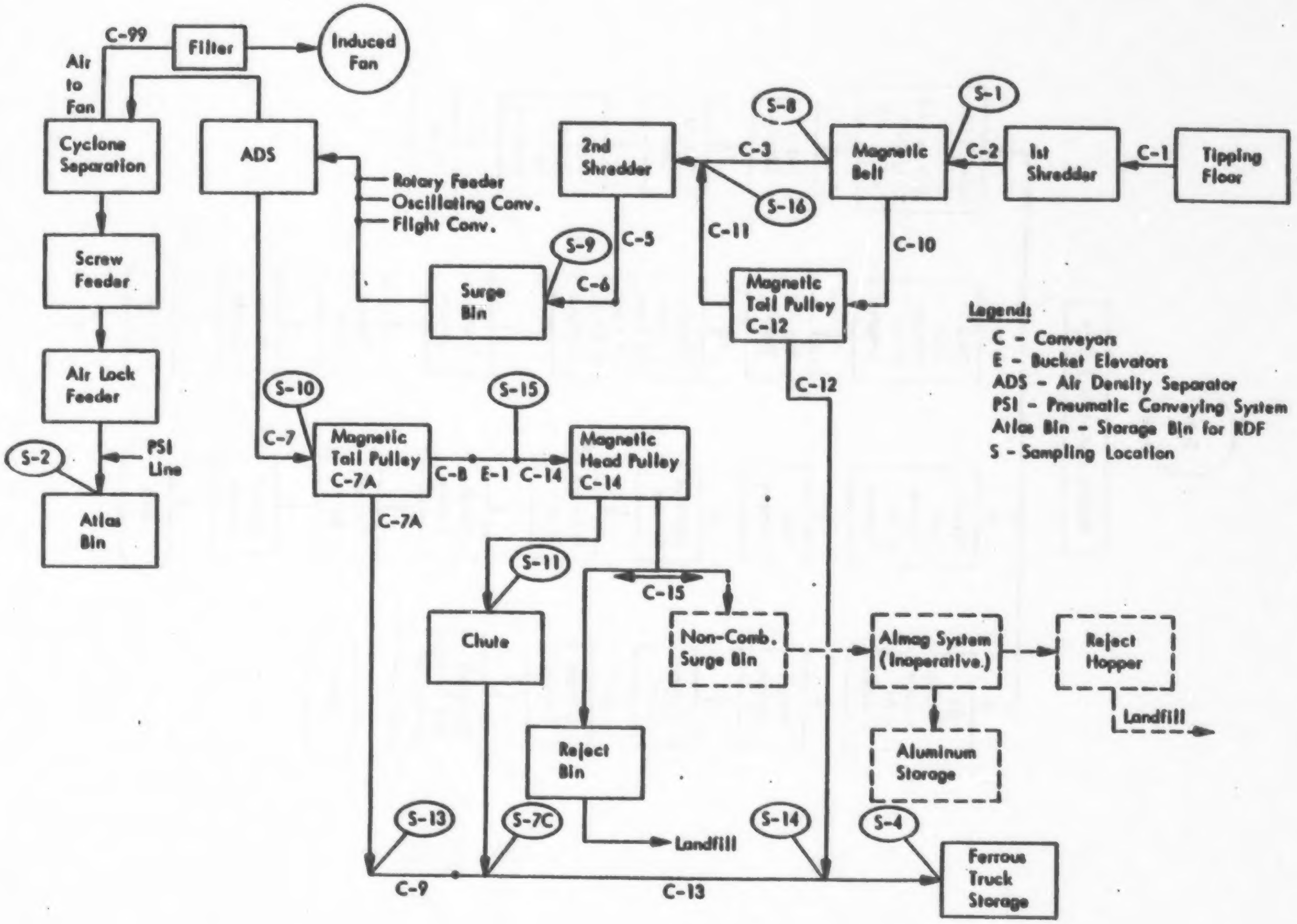
C-99
Air
to
Fan
Filter
Induced Fan
Cyclone Separation
ADS
Rotary Feeder
Oscillating Conv.
Flight Conv.
2nd Shredder
C-3
S-8
Magnetic Belt
S-1
C-2
1st Shredder
C-1
Tipping Floor
S-16
C-11
C-10
C-5
S-9
C-6
Surge Bin
Screw Feeder
Magnetic Tail Pulley C-12
Legend:
C - Conveyors
E - Bucket Elevators
ADS - Air Density Separator
PSI - Pneumatic Conveying System
Atlas Bin - Storage Bin for RDF
S - Sampling Location
Air Lock Feeder
C-12
S-10
S-15
S-2
PSI Line
C-7
Magnetic Tail Pulley C-7A
C-8
E-1
C-14
Magnetic Head Pulley C-14
Atlas Bin
C-7A
S-11
C-15
Chute
Non-Comb. Surge Bin
Almag System (Inoperative.)
Reject Hopper
Landfill
Reject Bin
Aluminum Storage
S-13
S-7C
Landfill
S-14
S-4
C-9
C-13
Ferrous Truck Storage

Figure 46. Flow diagram of Ames solid waste processing plant.

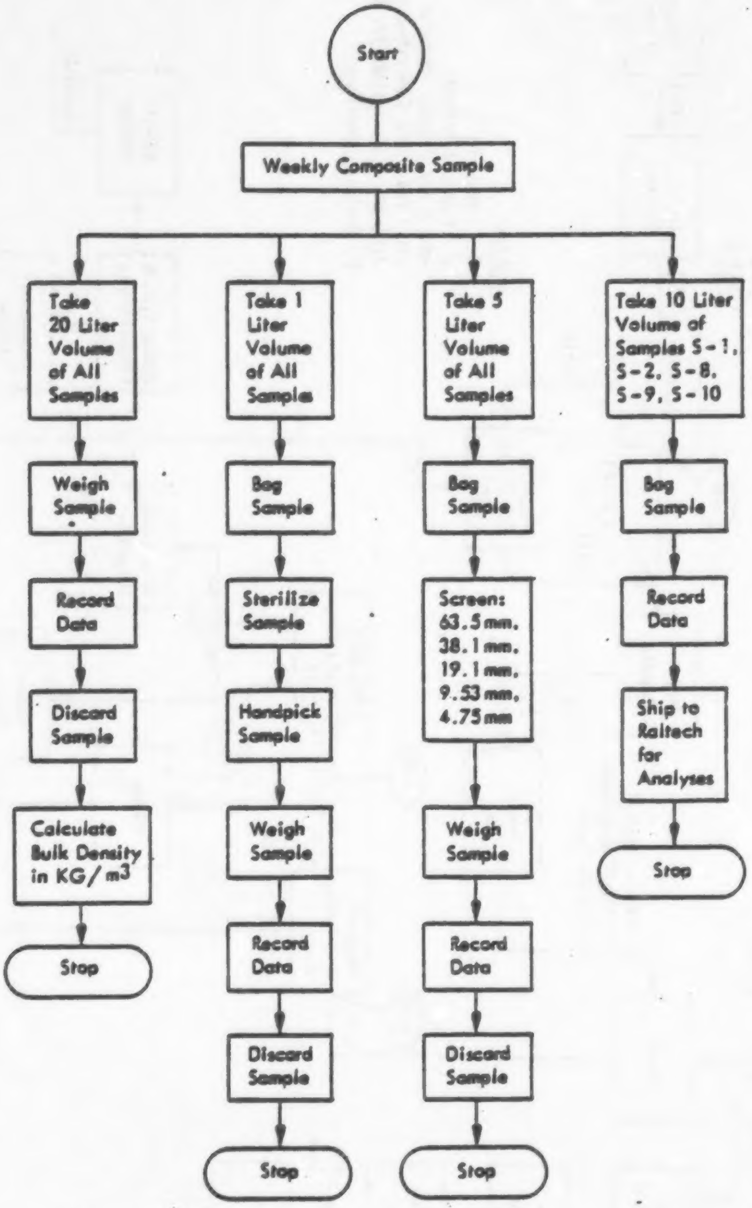
Start
Weekly Composite Sample
Take 20 Liter Volume of All Samples
Weigh Sample
Record Data
Discard Sample
Calculate Bulk Density in KG/m3
Stop
Take 1 Liter Volume of All Samples
Bag Sample
Sterilize Sample
Handpick Sample
Weigh Sample
Record Data
Discard Sample
Stop
Take 5 Liter Volume of All Samples
Bag Sample
Screen: 63.5 mm, 38.1 mm, 19.1 mm, 9.53 mm, 4.75 mm
Weigh Sample
Record Data
Discard Sample
Stop
Take 10 Liter Volume of Samples S-1, S-2, S-8, S-9, S-10
Bag Sample
Record Data
Ship to Raltech for Analyses
Stop

Figure 47. Flow chart - laboratory preparation of collected samples.

TABLE 30. ANALYSES PERFORMED ON PROCESS PLANT SAMPLES[a/]

Weekly composite sample I.D. No.	Description	Heating value, moisture, and ash	Metals by chemical analysis[b/]	Fixed carbon and volatile	Carbon, hydrogen, nitrogen, oxygen, and sulfur
S-1	Primary shredder discharge (C-2)	x	x		
S-2	RDF - inlet into Atlas storage bin	x	x	x	x
S-4	Ferrous metal - C-13				
S-7C	Magnetic Separator No. 4 - C-14				
S-8	Second stage shredder inlet feed - C-3 Dings on C-6	x	x		
S-9	Second stage shredder discharge	x	x		
S-10	ADS heavy discharge - C-7	x	x		
S-11	Heavies discharge C-15				
S-13	Magnetic Separator No. 2 - C-7A				
S-14	Magnetic Separator No. 3 - C-12				
S-15	Magnetic Separator No. 4 feed - Bucket Elevator E-1 discharge				
S-16	Magnetic Separator No. 3 return - C-11				

---

a/ All streams: Screening sized for 64, 38, 19, 9, 4, and 2 mm.
Handpick classifications:
1. Cardboard
2. Other paper
3. Plastic
4. Wood
5. Glass
6. Ferrous metal
7. Nonferrous metal
8. Natural, organic
9. Cloth
10. Tar
11. Misc. (sand, grit, rock, dust)

b/ Metals analyzed for aluminum, copper, iron, lead, nickel, and zinc.

Mixing on Friday also allowed for pasteurization of all samples at 105°C (221°F) over the weekend before handpick classification was started the following Monday.

Figure 48 is the flow chart of the sampling sequence. The sequence started at the top level, the third floor, and worked down through the second and first floors to the basement. The last sample was taken at the Atlas storage bin. The following is a detailed description of the sampling sequence.

Third Floor

1. Sample No. S-15 is magnetic separator No. 4 feed and is taken from bucket elevator E-1.

2. Sample No. S-11 is nonferrous metal separation system feed--noncombustible bin and is taken from conveyor C-15.

3. Sample No. S-7C is magnetic separator No. 4 discharge belt conveyor C-15 and is taken from the metal chute at the magnetic head pulley where C-14 dumps onto C-15.

Second Floor

4. Sample No. S-4 is ferrous material recovered at belt conveyor C-13.

First Floor

5. Sample No. S-9 is second stage shredder discharge (feed to the ADS system) and is taken at conveyor C-6.

Basement

6. Sample No. S-10 is ADS separation chute discharge (ADS heavies) and

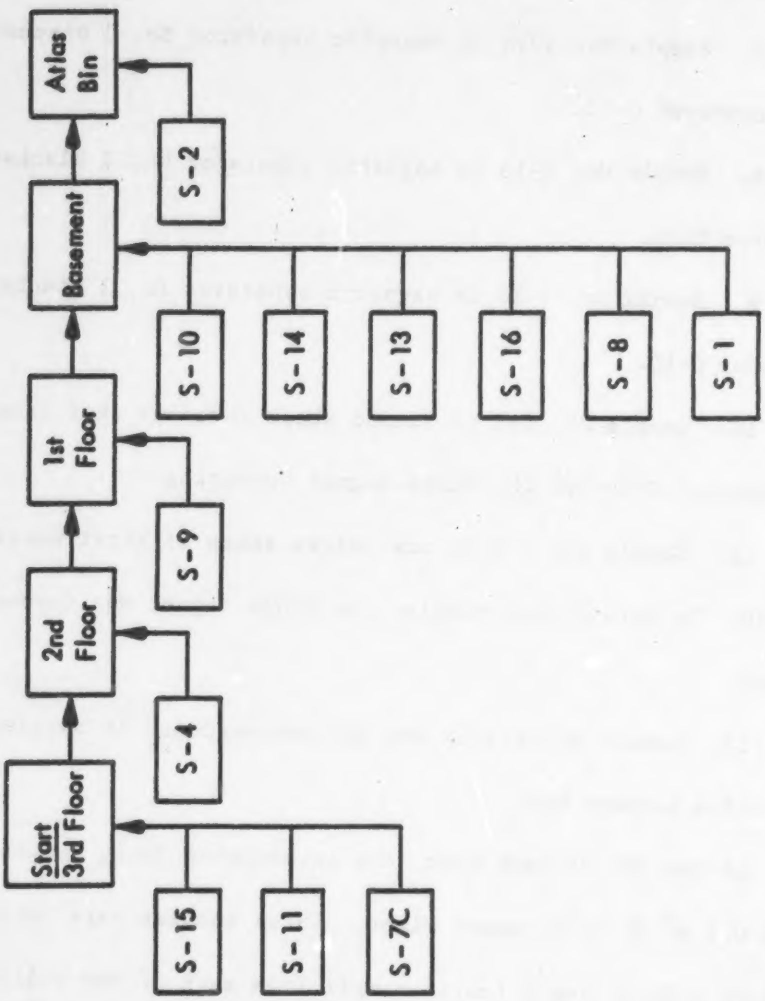
Start
3rd Floor
2nd Floor
1st Floor
Basement
Atlas Bin
S-15
S-11
S-7C
S-4
S-9
S-10
S-14
S-13
S-16
S-8
S-1
S-2

Figure 48. Processing plant sampling sequence flow chart.

is taken at conveyor C-7. To make this sample, the C-7 conveyor belt must be reversed so a reversing switch was installed to permit sampling at an accessible location by reversing the direction of the belt.

7. Sample No. S-14 is magnetic separator No. 3 discharge taken from belt conveyor C-12.

8. Sample No. S-13 is magnetic separator No. 2 discharge taken at belt conveyor C-7A.

9. Sample No. S-16 is magnetic separator No. 1 discharge taken at belt conveyor C-11.

10. Sample No. S-8 is second stage shredder feed taken at the discharge of conveyor C-2 with the Dings magnet operating.

11. Sample No. S-1 is raw refuse taken at first stage shredder discharge. To obtain this sample, the Dings magnet was turned off for about 15 sec.

12. Sample No. S-2 is the RDF produced and is sampled at the inlet to the Atlas storage bin.

At the end of each week, the accumulated daily samples were composited in a 0.2 m^3 (6 ft^3) cement mixer. Three samples were taken from each composited sample; and a fourth sample from each of the following: S-1, S-2, S-8, S-9, and S-10. Figure 46 shows the volume of sample taken from each composite and its dispensation.

The following is a list of the laboratory activities for a 1-week period. The laboratory week ran from Friday morning to Thursday evening.

Friday: Mixing, weighing, and screening. Deliver Ames samples to University power plant by 2:30 PM for shipment. Place samples in oven to be handpicked on Monday.

Monday: Handpick,[a] weigh, and record data.

Tuesday: Handpick,[a] weigh, and record data.

Wednesday: Complete handpicking and recording data. Perform calculations such as bulk density, samples net weight, percentages, etc., and log all information. Reserve truck for Thursday afternoon to pick up samples from process plant.

Thursday: Lab cleanup and preparation for incoming samples. All necessary supplies made ready. Pick up samples from process plant.

BULK DENSITY

Bulk density is the ratio of the weight of the material to its volume and is expressed as weight per unit volume. Bulk density measurements are dependent on particle size, method of loading the container, size of the container, and compaction of the material due to settling.

---

[a] Handpick categories include:
(a) cardboard
(b) other paper
(c) plastic
(d) wood
(e) glass
(f) Fe-metal
(g) non-Fe-metal
(h) natural organic
(i) miscellaneous
(j) other

The measurements of bulk density of the samples obtained at the 12 sampling locations were made by loosely filling a 20 liter container and immediately weighing the samples, then calculating the bulk density in units of kilograms per cubic meter from the measured weight of the 20 liter volume. It is interesting to note that the bulk density values measured very high during the week of October 28 through November 3, 1977, when bulk density reached 1,532 kg/m^3 from the ferrous material removed from the heavy stream at the tail pulley of conveyor C-14. This high bulk density measurement was due to the hammer change on both of the shredders during the week of September 30 through October 6, 1977. Whenever a hammer change is made on the shredders, bulk density measurements increase because of the better size reduction of the refuse.

Figure 49 gives the mean and standard deviation for bulk density measurements performed during the weeks of sampling. Tables 31 through 36 give the yearly average and seasonal averages for the bulk density, sizing, composition, laboratory analysis, and heating value of the flow stream. The mean for RDF is 99.93 kg/m^3. Bulk density measurements for conveyors C-2 and C-3 are quite similar in bulk density values, 99.38 kg/m^3 for C-2 and 93.08 kg/m^3 for C-3.

This flow stream consists mainly of nonferrous material such as cardboard, paper, sand, and grit. During sampling, the Dings magnet was shut off for approximately 15 sec so the flow stream would include ferrous materials. Slight differences in bulk density values are caused by the variation of the

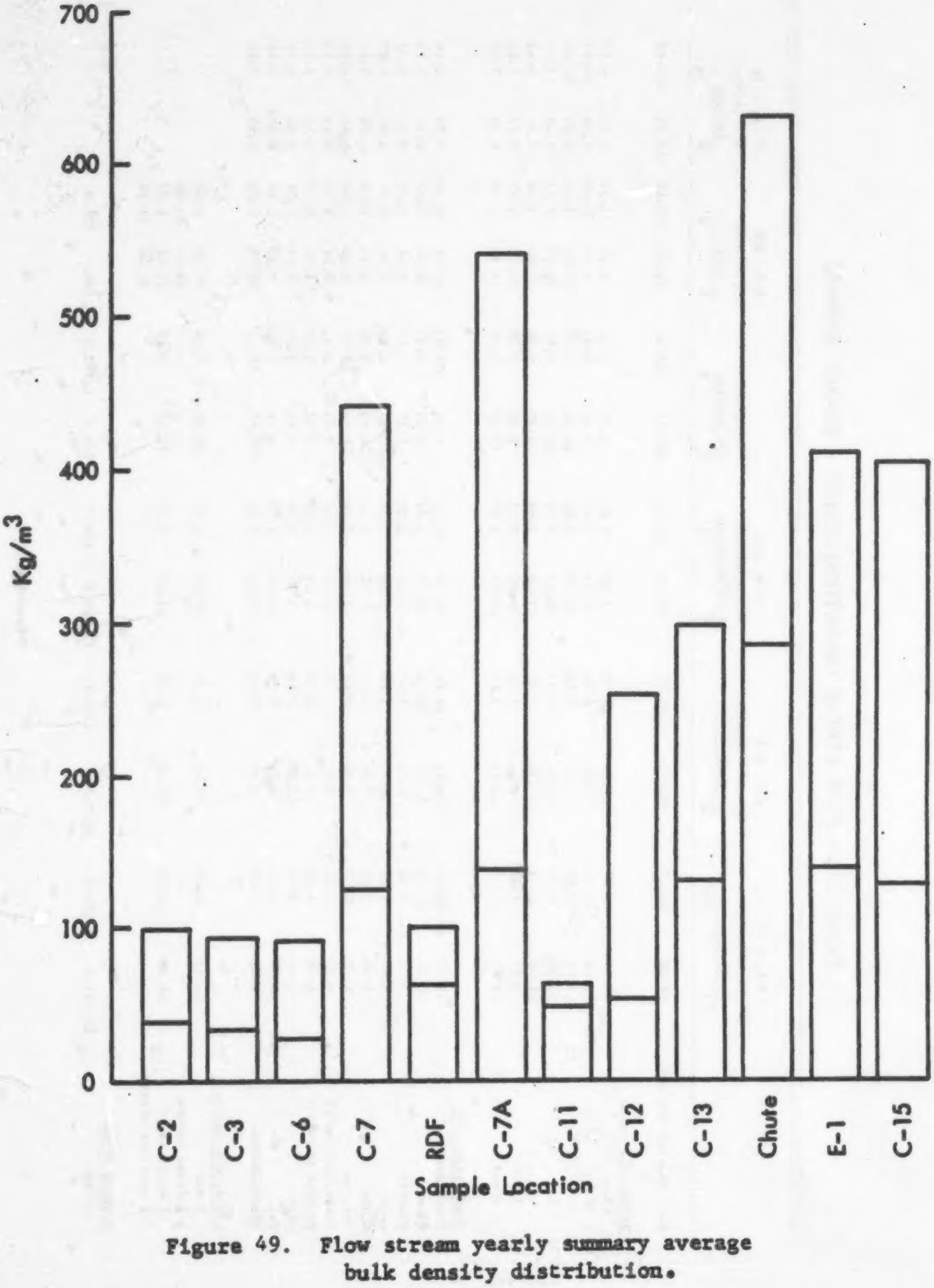

Figure 49. Flow stream yearly summary average bulk density distribution.

TABLE 31. FLOW STREAM CHARACTERIZATION - YEARLY SUMMARY

	S-1, C-2 First shredder discharge		S-8, C-3 Second shredder feed		S-9, C-6 Second shredder discharge		S-10, C-7 ADS heavies		S-2, RDF Atlas bin inlet		S-13, C-7A ADS heavies ferrous	
	$\bar{X}$ a/	s b/	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s
Bulk density (kg/m^3)	99.38	37.47	93.08	34.07	90.15	26.23	440.93	122.37	99.93	60.18	540.15	136.69
Sizing (%)												
63.5	24.67	17.07	25.74	18.19	3.60	4.05	3.32	4.34	5.15	5.21	4.16	6.17
38.1	12.18	7.23	12.53	6.20	9.57	6.00	9.92	8.23	9.97	6.18	38.74	15.83
19.1	16.14	5.49	14.80	4.80	20.12	5.50	24.81	7.59	15.16	3.56	35.49	10.44
9.5	14.29	4.43	14.73	5.17	22.27	3.99	22.16	4.66	20.02	4.50	12.28	7.59
4.8	11.09	3.59	11.33	5.05	16.62	3.90	15.95	5.26	17.06	3.34	5.84	3.62
2.4	7.95	2.81	8.04	3.50	10.03	3.01	9.90	3.85	10.92	2.31	2.17	1.61
Fines	14.62	5.12	14.19	5.05	19.47	7.01	15.29	5.79	23.37	7.14	1.69	2.07
Composition (%)												
Cardboard	12.17	12.46	14.71	14.86	16.33	10.06	1.61	1.87	16.42	8.46	0.35	0.64
Paper	34.36	12.91	31.62	14.72	38.93	8.83	6.06	2.90	38.54	9.02	0.74	0.74
Plastic	3.19	2.49	6.10	9.28	5.12	5.34	4.34	5.13	4.44	3.73	0.44	1.35
Wood	6.44	6.07	6.21	5.60	8.60	7.30	12.67	8.51	7.22	4.34	0.43	1.07
Glass	9.48	5.60	9.34	6.97	4.81	5.11	19.93	9.30	4.73	2.68	0.10	0.15
Ferrous	5.50	12.72	3.89	10.05	0.99	2.20	15.91	12.02	0.36	0.92	96.48	2.95
Nonferrous metal	0.87	3.11	0.78	2.75	0.60	1.17	3.93	5.33	0.81	1.74	0.23	1.33
Natural organics	6.59	6.26	7.25	7.15	3.97	3.92	7.02	6.02	3.79	3.33	0.19	0.39
Cloth	1.68	3.78	0.89	1.48	3.61	5.30	1.17	2.21	2.43	2.86	0.56	1.14
Tar	0.73	1.39	0.56	1.36	0.47	1.11	1.74	3.08	0.55	0.98	0.002	0.01
Miscellaneous	19.09	7.38	18.79	9.46	16.96	7.56	25.48	10.27	20.95	6.08	0.53	0.44
Laboratory analysis												
% ash	22.65	7.66	19.07	6.37	18.65	5.03	38.98	9.54	19.28	3.56		
% fixed carbon	-	-	-	-	-	-	-	-	28.19	11.88		
% moisture	24.20	6.54	25.38	6.69	23.43	5.87	16.14	5.40	22.05	6.77		
% volatile matter	-	-	-	-	-	-	-	-	30.48	11.54		
Heating value												
kJ/kg	11,237.3	1,007.2	11,567.8	1,121.1	12,268.4	988.7	9,959.1	1,373.9	12,108.1	751.3		

(continued)

TABLE 31. (continued)

	S-16, C-11 Dings magnet nonfe return		S-14, C-12 Dings magnet ferrous		S-4, C-13 Total ferrous output		S-15, E-1 ADS heavies nonfe		S-7C chute C-14 Tail pulley ferrous		S-11, C-15 ADS heavies rejects	
	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s
Bulk density (kg/m^3)	61.50	45.99	252.16	52.18	299.65	129.98	411.74	139.30	632.23	284.95	405.94	126.96
Sizing (%)												
63.5	35.56	20.66	51.07	19.02	36.85	21.24	3.53	6.03	2.43	4.09	2.95	4.34
38.1	11.32	11.59	37.91	16.17	39.06	16.94	6.99	5.36	9.04	9.04	7.64	6.04
19.1	18.85	17.28	6.96	6.14	15.41	9.86	24.50	7.95	28.45	10.36	25.44	8.52
9.5	14.92	10.01	2.45	2.89	5.42	8.00	23.49	3.87	27.52	8.32	23.87	4.06
4.8	7.42	4.68	0.94	1.03	1.94	1.63	16.06	5.11	14.82	4.57	15.91	4.80
2.4	4.01	2.14	0.38	0.34	0.78	0.68	10.03	5.22	6.42	2.38	9.59	3.56
Fines	8.56	8.14	0.36	0.61	0.65	0.75	17.14	7.80	12.33	6.70	16.18	7.18
Composition (%)												
Cardboard	4.40	6.97	0.12	0.37	0.49	1.05	3.20	4.23	2.12	3.32	3.77	6.48
Paper	33.43	23.19	1.02	1.92	0.87	0.77	7.72	3.72	4.76	3.68	8.09	3.70
Plastic	7.78	12.33	0.27	0.73	0.51	1.13	5.91	5.06	2.75	3.86	6.09	6.68
Wood	0.84	2.28	0.01	0.07	0.81	2.91	14.90	9.38	3.79	3.31	14.09	11.18
Glass	1.18	1.51	0.11	0.48	0.13	0.18	21.25	9.67	2.88	1.47	22.69	11.55
Ferrous metal	36.22	32.06	98.12	2.69	95.75	4.24	3.14	4.95	68.60	11.85	0.95	3.90
Nonferrous metal	1.76	11.25	0.01	0.04	0.05	0.18	6.29	5.96	1.59	2.58	5.89	6.53
Natural organics	1.53	2.70	0.04	0.11	0.47	1.67	7.76	5.54	1.34	1.53	7.32	5.23
Cloth	4.34	9.99	0.03	0.08	0.51	2.36	0.83	1.35	1.23	1.75	1.48	3.71
Tar	0.002	0.01	0.00	0.00	0.002	0.01	1.83	3.97	0.25	0.55	1.27	1.83
Miscellaneous	8.94	7.37	0.29	0.53	0.47	0.41	27.40	10.48	10.77	4.94	28.62	11.01
	-	-	-	-	-	-	-	-	-	-	-	-

(continued)

TABLE 31. (continued)

	S-1, C-2 First stage shredder discharge		S-8, C-3 Second shredder feed		S-9, C-6 Second shredder discharge		S-10, C-7 ADS heavies		S-2, RDF Atlas bin inlet	
	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
Higher heating value kJ/kg	11,237.3	1,007.2	11,567.8	1,121.1	12,268.4	988.7	9,951.1	1,373.9	12,108.1	751.3
Chloride (total) %									0.250	0.082
Proximate analysis (%)										
Ash	22.65	7.66	19.07	6.37	18.65	5.03	38.98	9.54	19.28	3.56
Fixed carbon	-	-	-	-	-	-	-	-	28.19	11.88
Moisture	24.20	6.54	25.38	6.69	23.43	5.87	16.14	5.40	22.05	6.77
Volatile matter									30.48	11.54
Ultimate analysis (%)										
Carbon (1)									29.74	3.48
Hydrogen									7.06	0.57
Nitrogen									0.41	0.08
Oxygen									42.31	6.26
Sulfur									0.36	0.12
Elemental analysis (%)										
Aluminum (2)	4.72	1.98	5.10	2.82	5.17	2.15	3.20	1.34	4.92	1.94
Copper	0.13	0.17	0.12	0.16	0.13	0.10	0.34	0.31	0.15	0.25
Iron	2.85	1.29	2.80	0.97	3.03	1.32	2.24	0.90	2.97	0.84
Lead	0.26	0.62	0.21	0.17	0.25	0.13	0.40	0.32	0.26	0.15
Nickel	0.06	0.03	0.06	0.02	0.07	0.04	0.08	0.04	0,06	0.02
Zinc	0.32	0.32	0.33	0.27	0.33	0.14	0.42	0.30	0.39	0.27

[a] X = Yearly average

[b] S = Seasonal average

TABLE 32. FLOW STREAM CHARACTERIZATION - SEASONAL SUMMARY
(SUMMER 7/5/77-9/22/77)

	S-1, C-2 First shredder discharge		S-8, C-3 Second shredder feed		S-9, C-6 Second shredder discharge		C-10, C-7 ADS heavies		S-2, RDF Atlas bin inlet		S-13, C-7A ADS heavies ferrous	
	$\bar{X}$ a/	s b/	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s
Bulk density (kg/m^3)	99.87	30.78	86.75	30.43	115.78	26.95	315.56	120.36	98.02	21.47	425.70	124.31
Sizing (%)												
63.5	30.67	16.91	31.00	16.24	2.51	3.81	1.73	3.03	3.64	3.82	4.48	5.48
38.1	13.80	8.69	16.37	5.31	9.92	5.78	14.75	12.46	8.09	3.11	39.13	16.57
19.1	17.52	7.10	17.34	6.74	18.67	4.54	28.07	6.44	13.44	3.15	36.32	10.61
9.5	13.07	3.47	13.02	5.49	20.70	3.87	22.66	5.95	19.23	2.65	10.72	8.10
4.8	6.92	3.09	8.16	3.94	18.02	4.46	14.33	5.59	20.01	3.02	5.37	3.98
2.4	7.27	3.80	5.07	1.29	7.03	6.11	7.97	4.59	12.90	1.80	0.30	0.36
Fines	13.60	4.25	12.83	4.84	28.43	8.08	16.11	7.47	31.68	7.67	3.93	3.51
Composition (%)												
Cardboard	19.04	8.84	23.15	16.91	19.56	7.38	3.16	1.89	21.64	8.87	0.84	0.96
Paper	39.77	14.34	21.79	8.23	40.33	6.62	6.89	3.67	31.74	7.52	0.92	0.66
Plastic	4.23	3.69	12.77	17.48	5.35	4.82	3.20	1.86	6.30	4.84	0.17	0.26
Wood	6.09	4.78	6.32	5.25	9.44	6.64	15.07	9.73	7.84	3.44	0.92	1.86
Glass	6.06	5.06	5.92	5.70	1.76	1.57	15.01	6.14	2.33	2.06	0.13	0.21
Ferrous metal	1.63	3.90	7.45	13.51	0.58	1.32	15.70	10.34	0.05	0.13	94.78	3.20
Nonferrous metal	0.23	0.46	0.51	0.87	0.19	0.29	6.12	9.79	1.51	2.85	0.89	2.81
Natural organics	3.43	2.87	5.76	5.22	2.63	2.29	8.38	9.08	2.75	1.44	0.16	0.27
Cloth	3.14	3.54	0.90	0.72	3.53	2.46	0.54	0.36	2.00	2.61	1.10	1.04
Tar	0.80	0.69	0.50	1.04	0.31	0.50	3.14	4.08	0.63	0.70	0.00	0.00
Miscellaneous	16.50	5.32	15.57	7.43	17.91	5.21	22.31	12.66	24.15	8.43	0.58	0.54

(continued)

TABLE 32. (continued)

	S-16, C-11 Dings magnet nonferrous return		S-14, C-12 Dings magnet Fe		S-4, C-13 Total ferrous output		S-15, E-1 ADS heavies nonferrous		S-7C (chute) C-14 Tail pulley ferrous		S-11, C-15 ADS heavies rejects	
	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
Bulk density (kg/m^3)	63.48	29.52	230.22	34.78	274.10	59.02	304.90	105.11	404.56	126.17	288.98	77.84
Sizing (%)												
63.5	37.15	20.38	53.21	23.74	37.82	26.32	1.97	2.32	1.56	2.35	2.29	2.32
38.1	11.42	5.71	36.97	20.05	41.40	19.10	7.90	6.61	8.04	8.97	6.81	5.01
19.1	26.54	21.03	6.62	7.11	14.32	13.05	27.14	8.76	34.14	7.47	26.22	8.06
9.5	11.52	6.32	1.72	2.29	3.10	3.54	23.89	3.54	24.51	5.72	24.25	3.04
4.8	5.91	5.05	0.87	1.43	1.89	2.32	15.31	5.67	16.09	5.37	17.25	4.76
2.4	4.70	1.78	0.10	0.10	0.90	1.30	2.77	3.43	3.97	4.11	7.17	3.80
Fines	6.28	4.81	0.62	1.24	1.21	1.30	23.11	11.19	14.56	4.93	21.38	8.82
Composition (%)												
Cardboard	6.83	9.08	0.03	0.06	1.07	1.72	5.78	5.93	5.07	5.56	8.38	8.52
Paper	34.60	22.64	1.26	3.80	0.88	0.94	10.52	5.24	7.75	4.27	11.73	3.97
Plastic	13.53	20.89	0.44	0.79	0.34	0.48	5.98	4.85	1.95	1.29	4.91	6.45
Wood	0.58	0.82	0.04	0.14	0.40	0.52	18.78	5.97	6.69	5.08	19.65	11.35
Glass	0.53	0.79	0.08	0.18	0.14	0.21	12.21	7.23	3.12	1.29	13.73	8.95
Ferrous metal	26.68	33.34	97.88	4.51	96.29	2.30	4.46	6.35	59.25	14.05	0.06	0.12
Nonferrous metal	0.43	1.47	0.02	0.06	0.06	0.14	6.85	4.89	0.99	1.19	5.25	6.01
Natural organics	1.91	3.35	0.00	0.00	0.07	0.10	5.15	5.10	2.11	1.98	3.91	2.16
Cloth	10.83	19.42	0.01	0.04	0.49	0.49	1.14	0.63	1.36	0.71	1.91	1.83
Tar	0.00	0.00	0.00	0.00	0.00	0.00	5.31	8.63	0.44	0.76	1.77	1.44
Miscellaneous	8.60	11.08	0.27	0.59	0.47	0.56	26.48	14.23	11.93	5.05	30.23	14.20

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[a] X = Yearly average

[b] S = Seasonal average

TABLE 33. FLOW STREAM CHARACTERIZATION - SEASONAL AVERAGE (FALL - 9/23/77-12/21/77)

	S-1, C-2 First shredder discharge		S-8, C-3 Second shredder feed		S-9, C-6 Second shredder discharge		S-10, C-7 ADS heavy rejects		RDF Atlas bin inlet		S-13, C-7A Ferrous removal ADS heavy rejects	
	$\bar{X}$ a/	S b/	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
Bulk density (kg/m^3)	101.29	31.60	92.27	41.87	92.72	19.01	438.03	125.73	99.97	23.81	524.08	135.23
Sizing (%)												
63.5 mm (2.5 in.)	18.09	14.55	20.93	16.21	3.46	3.28	2.54	3.79	7.22	5.45	3.79	6.03
38.1 mm (1.5 in.)	14.94	7.54	10.34	4.44	6.70	3.37	9.01	6.55	10.75	3.84	46.64	10.27
19.1 mm (0.75 in.)	17.24	5.08	15.99	4.35	19.55	7.17	23.39	5.88	14.55	3.09	33.77	7.96
9.5 mm (0.375 in.)	15.16	2.94	16.05	3.76	22.05	3.70	24.17	4.40	16.89	2.35	9.55	4.55
4.8 mm (No. 4)	12.48	2.67	13.58	5.04	18.75	4.24	18.05	5.12	16.51	2.96	4.28	1.89
2.4 mm (No. 8)	8.54	2.46	8.91	4.04	11.85	2.03	9.62	4.76	11.96	1.36	1.32	0.62
Fines mm	13.56	3.79	14.21	6.10	17.63	4.27	12.45	5.85	22.12	3.63	0.68	0.35
Composition (%)												
Cardboard	11.96	15.47	16.73	17.90	18.57	12.44	1.49	1.51	18.07	7.52	0.32	0.46
Other paper	33.18	11.18	35.20	16.71	36.78	11.86	5.62	2.55	34.18	7.55	0.53	0.28
Plastic	3.79	2.42	3.94	4.33	3.31	1.42	3.73	5.61	4.47	3.76	0.74	1.69
Wood	5.89	4.08	6.92	5.21	10.57	6.47	14.32	9.53	9.54	5.67	0.52	1.02
Glass	10.17	6.02	8.95	6.91	4.54	4.48	22.50	7.13	5.19	1.40	0.05	0.05
Ferrous metal	2.85	4.10	1.16	2.85	0.59	1.16	13.41	10.52	0.88	1.59	96.33	2.95
Nonferrous metal	0.19	0.31	1.72	4.58	0.78	1.13	3.83	2.30	0.35	0.61	0.05	0.14
Natural organics	6.91	7.75	4.66	4.02	2.42	1.65	3.98	3.22	3.72	2.36	0.27	0.64
Cloth	0.66	1.34	0.62	0.94	1.71	1.61	1.08	1.89	1.07	0.76	0.68	1.79
Tar	1.18	1.78	0.38	0.99	0.98	1.89	0.77	1.00	0.60	0.79	0.01	0.28
Miscellaneous	23.22	8.29	19.74	8.24	19.79	10.73	29.27	8.87	21.94	4.61	0.47	0.33

(continued)

TABLE 33. (continued)

	S-16, C-11 Dings magnet return		S-14, C-12 Dings magnet ferrous		S-4, C-13 Total ferrous output		S-15, E-1 ADS heavies		S-7C, C-14 Chute ferrous		S-11, C-15 Final rejects	
	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
Bulk density (kg/m³)	47.27	18.74	25.34	57.72	341.08	227.09	418.24	105.84	848.56	366.66	385.35	127.56
Sizing (%)												
63.5 mm (2.5 in.)	40.52	17.30	51.06	13.22	36.50	20.13	4.33	9.27	1.23	1.56	2.11	1.94
38.1 mm (1.5 in.)	7.12	7.50	38.65	12.52	42.64	18.56	6.39	4.58	12.69	10.84	7.88	5.90
19.1 mm (0.75 in.)	13.95	14.13	6.58	5.12	11.08	6.84	25.42	9.14	32.30	8.27	28.18	12.04
9.5 mm (0.375 in.)	20.45	11.38	2.33	3.64	7.23	14.52	24.49	4.68	26.95	9.66	25.93	3.95
4.8 mm (No. 4)	7.05	3.92	0.88	0.87	1.52	1.54	16.90	5.19	13.48	4.09	15.69	5.32
2.4 mm (No. 8)	4.17	1.76	0.33	0.33	0.60	0.67	9.17	4.28	5,79	1.94	9.05	4.08
Fines	6.73	2.67	0.23	0.16	0.43	0.51	13.29	6.69	7.52	2.29	11.15	6.28
Composition (%)												
Cardboard	2.28	3.02	0.12	0.22	0.32	0.47	2.71	2.37	1.25	1.13	3.08	4.38
Other paper	37.24	27.06	0.74	1.00	1.05	0.79	7.23	2.72	2.62	1.47	7.07	3.53
Plastic	7.82	12.33	0.08	0.19	0.30	0.55	5.80	4.93	2.50	3.19	4.94	5.17
Wood	0.39	0.64	0.01	0.03	0.62	1.10	18.84	11.17	3.14	2.49	17.01	9.19
Glass	1.55	1.36	0.02	0.06	0.15	0.14	23.28	8.35	2.18	1.11	23.93	12.74
Ferrous metal	32.41	29.71	98.82	1.13	95.82	3.63	2.46	3.63	75.42	8.50	2.93	7.64
Nonferrous metal	6.45	22.91	0.00	0.00	0.02	0.06	5.41	5.01	2.88	3.62	5.77	6.43
Natural organics	1.52	2.96	0.01	0.03	0.92	2.94	6.88	4.85	0.48	0.62	7.40	6.09
Cloth	1.01	1.30	0.04	0.11	0.23	0.46	0.86	1.27	1.08	1.72	0.48	0.49
Tar	0.00	0.00	0.00	0.00	0.00	0.00	0.92	1.29	0.08	0.17	1.01	1.24
Miscellaneous	9.34	6.32	0.15	0.20	0.60	0.42	25.61	7.18	8.35	3.05	26.43	8.75

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[a] X = Yearly average

[b] S = Seasonal average

TABLE 34. FLOW STREAM CHARACTERIZATION - SEASONAL AVERAGE (WINTER - 12/23/77-3/23/78)

	S-1, C-2		S-8, C-3		S-9, C-6		S-10, C-7		Atlas bin		Ferrous removal-ADS heavy rejects S-13, C-7A	
	$\bar{X}$ a/	S b/	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
Bulk density (kg/m^3)	78.26	36.28	85.67	31.17	64.77	11.31	542.17	73.69	79.43	15.49	609.94	79.22
Sizing (%)												
63.5 mm (2.5 in)	22.33	13.63	24.07	21.43	2.44	2.91	2.47	3.37	2.42	3.24	6.16	8.73
38.1 mm (1.5 in)	12.12	6.48	13.13	7.78	13.77	6.47	6.78	4.54	6.66	3.84	27.99	14.94
19.1 mm (0.75 in)	16.90	5.46	12.90	2.98	21.79	5.84	23.40	10.71	15.62	3.33	36.85	13.58
9.5 mm (0.375 in)	14.77	5.89	15.20	5.65	24.15	2.53	21.85	3.52	23.86	2.87	16.55	10.14
4.8 mm (No. 4)	10.63	3.90	11.50	5.57	14.14	2.04	18.08	5.40	16.91	2.62	8.18	4.56
2.4 mm (No. 8)	7.63	2.60	8.05	3.70	8.54	2.75	11.82	3.89	10.96	1.98	2.99	2.00
Fines	15.62	5.23	15.16	6.62	15.20	3.09	15.59	4.65	23.56	3.88	1.25	0.74
Composition (%)												
Cardboard	15.23	15.65	12.86	13.93	14.28	8.44	0.42	0.61	13.16	7.04	0.25	0.59
Other paper	32.08	15.05	37.68	12.93	42.77	8.42	6.54	2.97	42.83	6.81	0.35	0.27
Plastic	2.28	1.59	5.49	3.62	6.93	8.55	5.34	6.21	4.01	3.21	0.18	0.38
Wood	5.86	5.35	7.62	6.84	6.43	4.46	10.38	5.76	7.73	4.05	0.16	0.28
Glass	12.05	6.37	11.31	8.23	8.36	7.20	28.04	9.48	6.28	2.71	0.07	0.13
Ferrous metal	13.22	19.97	0.81	2.26	0.43	1.26	11.72	9.42	0.12	0.29	98.35	1.11
Nonferrous metal	0.18	0.28	0.91	3.15	1.08	1.92	1.97	1.66	1.12	2.06	0.01	0.03
Natural organics	3.50	2.73	7.13	7.21	2.73	1.91	9.62	5.57	1.52	1.12	0.08	0.22
Cloth	0.74	1.17	1.30	2.30	1.73	1.60	1.57	3.53	2.73	2.76	6.30	0.73
Tar	0.21	0.51	0.02	0.08	0.06	0.20	0.08	0.25	0.19	0.41	0.00	0.00
Miscellaneous	14.70	6.14	14.92	6.27	15.24	6.49	24.33	8.06	20.27	4.43	0.32	0.25

(continued)

TABLE 34. (continued)

	Dings magnet return S-16, C-11		Ferrous removal Dings (magnet) S-14, C-12		Total ferrous outlet S-4, C-13		ADS heavies S-15, E-1		Chute ferrous S-7C, C-14		Final heavies reject S-11, C-15	
	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
Bulk density (kg/m^3)	51.15	26.95	257.93	53.15	265.89	76.78	558.95	111.85	679.81	275.57	546.38	85.52
Sizing (%)												
63.5 mm (2.5 in)	33.95	21.92	44.13	10.23	34.32	16.89	2.09	2.33	0.92	1.37	2.61	4.45
38.1 mm (1.5 in)	15.78	17.29	43.74	15.44	36.14	14.22	5.52	4.39	6.52	8.84	6.39	5.96
19.1 mm (0.75 in)	12.99	14.59	6.87	5.53	20.05	8.63	20.47	5.62	24.63	13.14	23.23	6.69
9.5 mm (0.375 in)	11.42	5.73	3.15	2.60	5.91	3.96	23.74	3.42	33.82	6.59	25.38	3.61
4.8 mm (No. 4)	7.70	5.15	1.33	1.05	2.26	0.66	18.10	5.16	16.04	5.44	17.50	4.50
2.4 mm (No. 8)	4.06	2.89	0.42	0.37	0.85	0.59	13.99	5.83	7.12	2.36	10.96	3.31
Fines	14.08	14.29	0.32	0.20	0.42	0.23	16.13	3.53	10.98	5.00	13.92	3.72
Composition (%)												
Cardboard	3.98	5.20	0.18	0.43	0.12	0.31	0.87	0.95	0.72	0.95	1.04	1.05
Other paper	30.52	19.60	1.25	0.97	0.72	0.41	5.61	1.96	2.88	1.41	6.76	2.09
Plastic	4.20	4.65	0.16	0.30	0.60	1.67	6.32	6.64	2.48	2.63	7.38	4.44
Wood	0.35	0.44	0.00	0.00	0.32	0.94	10.47	9.14	2.99	2.25	8.14	5.65
Glass	1.43	2.41	0.05	0.19	0.09	0.12	29.98	8.78	3.02	1.38	33.21	7.94
Ferrous metal	43.15	30.36	98.01	1.51	97.28	1.91	3.28	6.72	73.81	8.80	0.45	1.50
Nonferrous metal	0.32	0.79	0.02	0.06	0.30	0.08	6.66	8.05	1.62	2.77	5.57	5.14
Natural organics	0.55	0.78	0.01	0.03	0.36	1.00	9.35	5.19	0.68	0.53	7.88	2.43
Cloth	4.68	8.77	0.04	0.08	0.05	0.10	0.15	0.17	0.52	0.83	1.91	4.40
Tar	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.86	0.00	0.00	0.24	0.46
Miscellaneous	10.83	8.13	0.28	0.18	0.44	0.36	27.01	8.09	11.24	6.70	27.29	5.74

a/ X = Yearly average

b/ S = Seasonal average

TABLE 35. FLOW STREAM CHARACTERIZATION - SEASONAL AVERAGE (SPRING - 3/24/78-6/22/78)

	S-1, C-2 First shredder discharge		S-8, C-3 Second shredder feed		S-9, C-6 Second shredder discharge		S-10, C-7 ADS heavy rejects		RDF Atlas bin inlet		S-13, C-7A Ferrous removal ADS heavy rejects	
	$\bar{X}$ a/	s b/	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s
Bulk density (kg/m^3)	106.49	37.49	99.11	29.86	90.05	23.73	456.38	56.53	115.28	111.71	613.61	129.81
Sizing (%)												
63.5 mm (2.5 in.)	29.92	20.56	30.16	19.33	4.88	4.97	5.11	5.78	5.14	4.79	2.98	4.37
38.1 mm (1.5 in.)	8.38	6.16	11.21	5.97	7.98	6.51	9.16	6.53	13.20	9.37	38.32	15.17
19.1 mm (0.75 in.)	13.58	4.43	13.31	3.99	19.54	4.47	24.75	5.74	15.98	4.07	36.35	9.62
9.5 mm (0.375 in.)	13.86	4.44	13.27	4.21	22.39	5.39	20.83	4.69	20.63	6.09	12.95	5.86
4.8 mm (No. 4)	11.31	3.48	10.52	4.11	16.15	3.34	13.76	3.55	15.94	3.52	5.66	2.89
2.4 mm (No. 8)	7.54	3.06	7.30	3.03	10.56	2.56	8.98	1.79	9.85	2.88	2.63	1.52
Fines mm	15.42	6.80	14.22	5.26	18.49	4.21	17.41	4.58	19.25	6.16	1.10	0.49
Composition (%)												
Cardboard	6.19	3.70	7.88	6.31	12.98	11.41	1.67	2.29	12.96	8.60	0.06	0.17
Other paper	31.99	10.22	30.98	17.16	36.75	6.76	5.25	2.86	43.76	8.97	0.73	0.76
Plastic	3.22	2.23	3.15	2.51	5.60	4.88	5.16	5.92	3.45	3.28	0.12	0.17
Wood	7.57	9.02	4.70	5.60	9.44	10.34	11.06	9.76	5.25	2.89	0.19	0.58
Glass	8.03	4.01	10.47	6.02	5.35	4.29	15.63	6.48	5.45	2.96	0.11	0.18
Ferrous metal	4.28	12.54	7.22	14.81	2.18	3.74	18.03	11.82	0.38	0.85	97.60	1.45
Nonferrous metal	2.89	5.85	0.02	0.06	0.40	0.80	4.33	5.00	0.27	0.51	0.08	0.18
Natural organics	10.43	6.75	10.17	8.87	6.12	5.34	7.22	5.15	5.56	4.72	0.14	0.22
Cloth	2.92	6.48	0.55	0.97	4.95	6.10	1.38	1.70	3.71	3.91	0.32	0.49
Tar	0.53	1.62	1.14	2.21	0.48	0.78	3.62	4.38	0.58	1.33	0.00	0.00
Miscellaneous	21.91	6.78	23.70	13.25	15.73	6.49	26.66	11.26	18.59	5.80	0.62	0.53

(continued)

TABLE 35. (continued)

	S-16, C-11 Dings magnet return		S-14, C-12 Dings magnet ferrous		S-4, C-13 Total ferrous output		S-15, E-1 ADS Heavies		S-7C, C-14 Chute ferrous		S-11, C-15 Final rejects	
	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
Bulk density (kg/m³)	86.48	79.20	260.68	56.36	312.20	87.32	373.02	118.50	599.81	121.88	416.56	59.10
Sizing (%)												
63.5 mm (2.5 in.)	28.54	21.46	56.49	21.62	41.00	23.87	5.33	7.00	5.71	6.65	3.05	4.05
38.1 mm (1.5 in.)	12.09	12.56	33.57	17.41	33.72	16.35	7.58	5.89	7.25	6.27	7.15	4.69
19.1 mm (0.75 in.)	21.89	17.93	5.81	5.11	16.34	9.21	25.58	8.05	22.48	7.67	24.55	6.72
9.5 mm (0.375 in.)	16.14	12.58	2.27	3.27	5.53	5.56	22.52	3.88	25.21	7.59	21.22	3.45
4.8 mm (No. 4)	9.23	4.82	0.66	0.17	1.91	1.73	13.53	4.31	14.64	3.25	14.42	2.78
2.4 mm (No. 8)	3.98	1.89	0.48	0.37	0.90	0.71	8.42	3.34	7.12	2.33	9.78	7.06
Fines mm	8.13	3.38	0.30	0.29	0.58	0.39	17.03	6.35	17.62	9.25	19.81	3.88
Composition (%)												
Cardboard	3.38	8.47	0.16	0.58	0.42	1.11	3.65	5.21	1.87	2.68	1.27	1.31
Other paper	31.78	76.01	0.64	0.52	0.58	0.39	6.85	2.36	4.93	1.73	6.98	3.29
Plastic	6.25	6.45	0.07	0.17	0.81	1.46	6.08	4.57	4.61	6.56	7.36	10.09
Wood	0.96	1.51	0.00	0.00	1.77	5.79	11.24	8.74	3.12	2.02	10.52	12.88
Glass	1.37	0.94	0.03	0.09	0.09	0.14	19.70	5.68	2.85	1.87	21.06	5.65
Ferrous metal	44.67	33.90	98.49	1.24	94.02	7.04	2.68	3.00	64.56	10.20	0.33	0.96
Nonferrous metal	0.12	0.39	0.01	0.03	0.00	0.00	5.85	5.77	1.03	1.92	6.04	6.20
Natural organics	1.21	1.09	0.11	0.21	0.54	1.49	9.70	6.69	2.27	1.77	9.82	7.33
Cloth	3.10	9.19	0.02	0.04	1.35	4.56	1.10	1.98	2.24	2.62	1.92	5.65
Tar	0.01	0.03	0.00	0.00	0.00	0.00	1.93	2.50	0.61	0.82	2.33	2.78
Miscellaneous	7.17	3.18	0.48	0.89	0.41	0.51	31.22	12.30	11.92	5.28	32.40	13.39

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a/ X = Yearly average

b/ S = Seasonal average

TABLE 36. FLOW STREAM CHARACTERIZATION - SEASONAL AVERAGE (SUMMER - 6/23/78-7/13/78)

	S-1, C-2 First shredder discharge		S-8, C-3 Second shredder feed		S-9, C-6 Second shredder discharge		S-10, S-7 ADS heavy rejects		RDF Atlas bin inlet		S-13, C-7A ADS heavy rejects	
	$\bar{X}$ a/	s b/	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s
Bulk density (kg/m^3)	106.49	37.49	99.11	29.86	90.05	23.73	456.38	56.53	115.27	111.71	613.61	129.81
Sizing (%)												
63.5 mm (2.5 in.)	22.53	23.61	13.53	7.26	8.10	5.85	7.87	3.16	12.40	8.80	0.90	1.56
38.1 mm (1.5 in.)	12.07	5.50	9.67	4.82	9.37	3.25	11.17	14.22	10.67	3.65	51.33	19.42
19.1 mm (0.75 in.)	14.97	5.96	14.13	3.45	23.60	1.28	26.50	10.36	17.83	3.97	30.07	11.98
9.5 mm (0.375 in.)	14.00	7.13	20.07	8.52	20.73	1.94	18.80	3.91	17.57	1.68	8.93	4.25
4.8 mm (No. 4)	12.67	6.09	17.07	11.59	14.57	2.20	12.50	5.57	14.40	1.30	5.03	3.40
2.4 mm (No. 8)	9.20	4.37	10.47	1.46	9.30	1.14	8.73	4.58	10.03	1.63	2.13	0.99
Fines mm	14.53	5.74	15.10	1.41	14.30	0.89	14.43	7.55	17.07	1.64	1.53	0.59
Composition (%)												
Cardboard	5.03	0.64	9.77	11.80	16.40	6.13	1.87	2.06	17.10	6.46	0.20	0.26
Other Paper	43.40	16.54	31.93	4.34	36.70	10.43	6.70	1.25	42.60	0.53	2.60	0.87
Plastic	1.33	1.59	4.23	3.22	2.77	2.21	2.83	1.53	3.13	0.31	2.73	4.47
Wood	7.50	7.35	3.17	1.91	1.73	2.92	14.47	1.25	3.30	4.11	0.23	0.25
Glass	11.97	1.45	11.33	9.46	1.67	1.55	8.73	6.47	3.50	1.39	0.23	0.12
Ferrous Metal	0.50	0.87	0.47	0.81	1.47	1.40	36.37	18.79	0.30	0.52	91.30	3.98
Nonferrous Metal	0.00	0.00	0.57	0.67	0.43	0.45	3.90	6.75	1.20	1.04	0.00	0.00
Natural Organics	11.43	5.50	12.33	13.09	11.80	2.19	3.47	3.57	7.70	2.86	0.60	0.36
Cloth	1.30	1.84	1.73	2.27	13.67	13.43	0.40	0.44	1.87	1.93	0.93	1.29
Tar	1.77	1.91	1.27	0.90	0.17	0.15	1.77	1.59	1.23	1.80	0.00	0.00
Miscellaneous	15.73	1.11	23.10	4.52	13.10	7.40	19.40	11.41	18.13	2.45	1.00	0.00

(continued)

TABLE 36. (continued)

	S-16 (C-11) Dings magnet return		S-14 (C-12) Dings magnet ferrous		S-4 (C-13) Total ferrous output		S-15 (E-1) ADS heavies		S-15 (C-14) Chute ferrous		S-11 (C-15) Final rejects	
	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
Bulk density (kg/m³)	86.48	79.20	260.86	56.36	312.20	87.32	373.02	118.50	599.81	121.88	416.56	59.09
Sizing (%)												
63.5 mm (2.5 in.)	45.03	30.71	49.13	10.06	27.57	17.03	5.45	5.59	4.17	5.75	10.20	11.96
38.1 mm (1.5 in.)	6.50	4.16	32.13	11.30	50.00	13.08	9.83	6.07	14.90	9.45	17.40	10.76
19.1 mm (0.75 in.)	21.83	16.05	15.33	10.46	14.30	11.35	22.77	2.71	31.30	9.61	23.97	6.38
9.5 mm (0.375 in.)	14.53	12.45	1.73	0.95	4.20	4.94	20.73	3.09	22.90	9.58	18.33	2.96
4.8 mm (No. 4)	6.10	3.15	1.00	0.95	2.70	1.77	17.53	1.82	11.43	2.02	11.07	8.40
2.4 mm (No. 8)	2.47	1.69	0.33	0.15	0.57	0.55	10.77	1.59	5.73	0.67	7.63	6.60
Fines mm	3.57	1.63	0.37	0.25	0.60	0.46	14.73	3.30	9.60	2.01	11.30	6.81
Composition (%)												
Cardboard	10.03	8.27	0.00	0.00	0.70	0.62	3.20	1.75	2.13	2.74	11.07	16.83
Other Paper	31.97	22.40	1.90	1.35	2.00	1.56	11.50	3.37	10.47	7.91	8.60	1.74
Plastic	6.77	6.41	1.67	2.45	0.40	0.46	3.67	1.70	0.57	0.57	4.80	4.96
Wood	5.40	9.09	0.00	0.00	1.17	0.85	17.47	3.15	2.20	1.25	20.43	17.25
Glass	0.23	0.40	1.13	1.96	0.30	0.52	17.47	8.21	4.57	0.92	14.60	15.00
Ferrous Metal	24.30	42.09	94.93	5.40	94.20	3.15	2.00	2.78	66.97	7.75	0.00	0.00
Non-Ferrous Metal	0.00	0.00	0.00	0.00	0.40	0.69	8.17	7.45	0.30	0.30	9.93	16.35
Natural Organics	5.73	5.85	0.10	0.10	0.27	0.23	6.73	3.27	1.47	1.61	7.47	2.55
Cloth	7.50	6.32	0.07	0.11	0.10	0.17	1.73	2.06	0.57	0.55	1.00	0.89
Tar	0.00	0.00	0.00	0.00	0.03	0.06	4.17	5.57	0.23	0.21	1.03	1.38
Miscellaneous	8.07	4.45	0.20	0.17	0.37	0.38	23.93	6.78	10.47	0.81	20.97	11.47

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a/ X = Yearly average

b/ S = Seasonal average

material composition. Conveyor C-6 represents a slightly lower bulk density value of 90.15 kg/m^3 compared to C-2 and C-3. An analysis of the seasonal averages indicates that a combination of high paper and cardboard composition and hammer deterioration contributes to an increased number of fines and subsequently higher bulk density.

The bulk density of the first shredder discharge for the summer of 1977 (July 5 to September 22, 1977) was 99.87 kg/m^3 and remained relatively constant through the fall of 1977 (September 23 to December 21, 1977) at 101.29 kg/m^3. This is in contrast to the bulk density of the second shredder discharge which was 115.78 kg/m^3 for the summer of 1977 and 92.72 kg/m^3 for the fall of 1977. A possible explanation is that the hammers were changed in both shredders the week of October 12, 1977, and the percentage of paper and cardboard decreased from 59 to 45% from summer to fall. This variation in bulk density raises the possibility that, as hammer wear occurs, the material tends to remain in the shredder rather than being pushed out. This increase in retention time would result in more fines and a resultant increase in bulk density.

Relatively high density flows are associated with the ADS (reject) streams (440.93 kg/m^3); specifically, these include the bottom flow C-7, ferrous material removed from the bottom flow C-7A, and ferrous material removed at the end of the C-14 belt flow (chute). The explanation for the high density value is that the ADS system removes light material aerodynamically, leaving the reject material with a relatively high mass-to-area ratio that tends to be collected as a high density flow.

SECTION 10

COMPARISON OF PROCESSING PLANT OPERATIONS BEFORE AND AFTER INSTALLATION OF DISC SCREENS AND DUST COLLECTION SYSTEM

FLOW STREAM SAMPLING BEFORE AND AFTER MODIFICATION

Sampling was conducted for 8 weeks in 1979 beginning February 26 and ending April 16 to get an indication of the system performance resulting from addition of the disc screen system. The corresponding 8 weeks of the previous year, February 24 to April 20, 1978, were selected for comparison, which should give representative refuse input characteristics for the winter-spring seasons.

COMPARISON OF BULK DENSITY, SIZING, AND COMPOSITION

The various material flow streams associated with the disc screens were analyzed for the physical properties of bulk density, particle size distribution, and visual composition. These properties were then compared, before and after the disc screen installation, to determine the effect of the disc screens. Following is a discussion of each individual material flow stream.

First Stage Shredder Discharge after Dings Belt Magnet Ferrous Removal

Table 37 gives the bulk density, sizing, and composition of the process plant feed which before the modification was the second shredder feed and

TABLE 37. FIRST STAGE SHREDDER DISCHARGE COMPARISON BEFORE AND AFTER MODIFICATION - (8 Weeks Sampling)

	(2/24-4/20/78) Before modification 2nd shredder feed (C-3)	(2/26-4/16/79) After modification 1st disc screen feed (C-2A)
Bulk density	86.08 kg/m^3	53.28 kg/m^3
Sizing-mm	%	%
64	31.95	43.51
38	11.66	15.24
19	12.80	12.37
9.5	13.91	9.40
4.8	9.40	7.13
2.4	6.91	4.46
Fines	13.36	7.91
Composition	%	%
Cardboard	9.16	17.96
Other paper	37.24	46.50
Plastic	5.25	4.29
Wood	6.63	10.03
Glass	10.38	4.86
Ferrous	1.39	0.71
Nonferrous	0.00	1.81
Natural organic	7.65	4.10
Cloth	1.44	0.63
Tar	0.04	0.00
Miscellaneous	20.82	9.08

after modification became the feed to the first disc screen. The bulk density decreased from 86 to 53 kg/m^3, and the size of the material generally increased, as indicated by the percent increase in the 64 and 38 mm fractions and the decrease in the 19 mm and smaller fractions. The fines collected were also reduced.

There was an increase in cardboard, paper, and wood; but all other classifications decreased. These shifts may be indicative of a change in raw refuse between the 2 years.

Second Shredder Infeed

Table 38 gives the bulk density, sizing, and composition analysis of the second shredder feedstock before and after modification. The purpose of this comparison was to observe the effect of the first disc screen, which scalps the oversize material for second shredding, hence reducing the mass flow through the second shredder. After modification, the bulk density was about one-half, the sizing above 19 mm increased, and the fines dropped from 13.36 to 2.61%.

There was a large increase in cardboard and ferrous, a moderate increase in paper, and a large decrease in glass, natural organics, and miscellaneous. The glass and miscellaneous categories included the gritty types of material which did not go through the second shredder after the modification was made.

TABLE 38. SECOND STAGE SHREDDER INFEED COMPARISON BEFORE AND AFTER MODIFICATION - (8 Weeks Sampling)

	(2/24-4/20/78) Before modification 2nd shredder feed (C-3)	(2/26-4/16/79) After modification 1st disc screen oversize (C-3)
Bulk density	86.08 kg/m^3	40.36 kg/m^3
Sizing-mm	%	%
64	31.95	58.93
38	11.66	20.41
19	12.80	13.24
9.5	13.91	2.61
4.8	9.40	1.51
2.4	6.91	1.13
Fines	13.37	2.17
Composition	%	%
Cardboard	9.16	28.04
Other paper	37.24	42.64
Plastic	5.25	3.07
Wood	6.63	2.90
Glass	10.34	0.00
Ferrous	1.38	19.70
Nonferrous	0.00	0.07
Natural organic	7.65	1.57
Cloth	1.44	0.14
Tar	0.04	0.00
Miscellaneous	20.82	1.83

ADS System Input

Table 39 gives the bulk density, sizing, and composition analysis of the feed to the ADS system. After modification, the bulk density was somewhat lower. The material sizing had reduced tails; 64 mm particulate screen fractions were reduced from 4.28 to 1.71% and fines from 16.19 to 7.16%. Since the 38, 19, and 9 mm screen fractions were all increased, it can be concluded that sizing was more uniform after the modification.

Material composition showed a large drop in wood, natural organics, and miscellaneous categories and a large increase in metals, both ferrous and nonferrous. The metals increase was due to several weeks of large metal fractions being obtained in the sample analysis; long-run sampling would probably not yield these large percentages.

RDF

The RDF shows some significant changes in a number of characteristics as seen in Table 40. The bulk density was about one-half its former value, 84.45 kg/m^3 in 1978 versus 41.70 kg/m^3 in 1979. Reasons for this change were the shifts in sizing. The small fractions, fines, 2.4 and 4.8 mm were reduced; the mid-range, 9.5, 19, and 38 mm, fractions were increased; and the 64 mm fraction was unchanged. Another reason for the drop in bulk density and also the shift in sizing was the change in RDF composition. There was a reduction in wood, glass, metals, and nonclassifiable or miscellaneous material, and these constituents are relatively high density

TABLE 39. ADS INFEED COMPARISON BEFORE AND AFTER MODIFICATION - (8 Weeks Sampling)

	(2/24-4/20/78) Before modification 2nd shredder discharge (C-6)	(2/26-4/16/79) After modification ADS feed (C-6)
Bulk density	76.88 kg/m^3	60.35 kg/m^3
Sizing-mm	%	%
64	4.28	1.71
38	11.19	15.83
19	22.39	29.43
9.5	21.38	27.93
4.8	15.13	12.53
2.4	9.48	5.41
Fines	16.15	7.16
Composition	%	%
Cardboard	15.14	19.31
Other paper	43.09	43.01
Plastic	4.87	5.59
Wood	10.79	3.29
Glass	3.56	3.12
Ferrous	0.91	7.77
Nonferrous	0.54	7.15
Natural organic	5.00	1.88
Cloth	2.01	1.26
Tar	0.07	1.71
Miscellaneous	14.02	5.89

TABLE 40. COMPARISON BEFORE AND AFTER MODIFICATION
(8 Weeks Sampling)

	(2/24-4/20/78) Before modification Atlas bin inlet (RDF)	(2/26-4/16/79) After modification Atlas bin inlet (RDF)
Bulk density	84.45 kg/m^3	41.70 kg/m^3
Sizing-mm	%	%
64	4.29	4.83
38	9.81	13.94
19	15.34	33.21
9.5	20.45	24.80
4.8	16.59	10.53
2.4	11.35	4.86
Fines	22.17	7.83
Composition	%	%
Cardboard	10.43	29.26
Other paper	42.44	49.50
Plastic	3.95	5.13
Wood	8.21	4.28
Glass	6.05	1.44
Ferrous	0.21	0.14
Nonferrous	1.29	0.58
Natural organic	4.21	1.49
Cloth	3.54	1.59
Tar	0.23	0.00
Miscellaneous	19.44	6.59

components of RDF. The cardboard, paper, and plastic categories increased, and these tend to be lower density, larger materials. After the addition of the disc screen system, the general appearance of the RDF was more "fluffy" than it had been.

The RDF sizing showed a definite shift, with the maximum occurring at 19 mm instead of at the fines; the fines decreased from 22.17 to 7.83%. There was only a slight increase in the 64 mm class, from 4.29 to 4.83%; hence, the mean size increased, but the maximum size did not.

The RDF samples indicated a marked improvement in "quality." The cardboard and paper fractions increased substantially, while the glass dropped considerably. The metal content and the miscellaneous materials decreased also. The reduction in the glass and miscellaneous content will result in less wear of the pneumatic transport and retrieval systems.

ADS Heavies

The bulk density, sizing, and composition characteristics are shown in Table 41 for the ADS rejects. The bulk density decreased from 491.13 to 313.86 kg/m^3. There was a reduction in the smaller fractions, fines through 4.8 mm; the mid-range, 9.5 and 19 mm, fractions were increased; and the larger size, 38 and 64 mm, fractions were virtually unchanged. This trend is very similar to what happened to RDF.

Composition showed an increase in cardboard (1.80 to 4.23%), ferrous metal (8.09 to 28.44%), and nonferrous metal (1.65 to 8.74%). There was a decrease in glass (18.76 to 10.63%) and miscellaneous (28.36 to 10.08%).

TABLE 41. ADS HEAVIES COMPARISON BEFORE AND AFTER MODIFICATION - (8 Weeks Sampling)

	(2/24-4/20/78) Before modification ADS heavies (C-7)	(2/26-4/16/79) After modification ADS heavies (C-7)
Bulk density	491.13 kg/m^3	313.86 kg/m^3
Sizing-mm	%	%
64	3.94	3.79
38	11.74	11.84
19	24.66	37.76
9.5	20.78	30.90
4.8	14.49	10.57
2.4	8.94	3.13
Fines	15.46	2.06
Composition	%	%
Cardboard	1.80	4.23
Other paper	7.14	7.99
Plastic	9.29	10.75
Wood	12.19	10.29
Glass	18.76	10.63
Ferrous	8.09	28.44
Nonferrous	1.65	8.74
Natural organic	10.93	8.04
Cloth	0.40	0.50
Tar	1.41	0.36
Miscellaneous	28.36	10.08

Ferrous Magnetic Separation (Dings Belt)

The sampling results of the Dings belt magnet (magnetic separator No. 1) after cleanup by magnetic separator No. 3 are given in Table 42. There was a slight increase in bulk density from 255.48 to 294.89 kg/m^3, and the sizing showed a slight reduction in material smaller than 19 mm and an increase in material larger than 19 mm.

There were no significant changes in composition; the shifts in sizing may have been indicative of the sizing changes at the first shredder discharge.

Magnetic Separator No. 4

Table 43 gives the bulk density, sizing, and composition of material removed by the second ferrous removal system on the ADS heavies stream. After the modification this material joined the system rejects rather than the ferrous output because of the lack of ferrous purity in the heavies stream.

The bulk density decreased from 653.35 to 527.83 kg/m^3; there was an increase in material larger than 19 mm; the largest increase was in the 38 mm size. Material composition did not change appreciably. The ferrous content increased from 66.13 to 67.38%, while the miscellaneous or nonclassifiable content dropped from 14.35 to 3.43%.

Output Ferrous Stream

The total ferrous output characteristics from the system are given in Table 44. The bulk density and sizing were essentially unchanged. The composition showed a slight increase in ferrous content from 97.30 to 98.69%; nonferrous and cloth were the only contaminants showing any increase.

TABLE 42. FERROUS MAGNETIC BELT SEPARATION COMPARISON BEFORE AND AFTER MODIFICATION - (8 Weeks Sampling)

	(2/24-4/20/78) Before modification Dings magnet ferrous (C-12)	(2/26-4/16/79) After modification Dings magnet ferrous (C-12)
Bulk density	255.48 kg/m^3	294.89 kg/m^3
Sizing-mm	%	%
64	47.01	56.30
38	41.01	32.86
19	6.15	7.84
9.5	3.35	1.90
4.8	1.43	0.56
2.4	0.65	0.40
Fines	0.40	0.14
Composition	%	%
Cardboard	0.08	0.14
Other paper	0.86	0.69
Plastic	0.16	0.53
Wood	0.00	0.00
Glass	0.00	0.00
Ferrous	98.13	98.39
Nonferrous	0.03	0.01
Natural organic	0.15	0.10
Cloth	0.01	0.01
Tar	0.00	0.00
Miscellaneous	0.60	0.16

TABLE 43. FERROUS MAGNETIC SEPARATOR NO. 4 COMPARISON BEFORE AND AFTER MODIFICATION - (8 Weeks Sampling)

	(2/24-4/20/78) Before modification C-14 tail pulley ferrous (chute)	(2/26-4/16/79) After modification C-14 tail pulley ferrous (chute)
Bulk density	653.35 kg/m^3	527.83 kg/m^3
Sizing-mm	%	%
64	4.34	5.56
38	5.11	25.43
19	22.51	28.19
9.5	29.71	24.33
4.8	16.76	10.30
2.4	7.90	3.07
Fines	13.69	3.14
Composition	%	%
Cardboard	2.18	2.60
Other paper	4.33	5.74
Plastic	3.38	6.50
Wood	3.06	5.75
Glass	2.80	2.26
Ferrous	66.13	67.38
Nonferrous	1.29	2.76
Natural organic	1.01	2.73
Cloth	1.28	0.63
Tar	0.16	0.21
Miscellaneous	14.35	3.43

TABLE 44. TOTAL FERROUS OUTPUT COMPARISON BEFORE AND AFTER MODIFICATION - (8 Weeks Sampling)

	(2/24-4/20/78) Before modification total ferrous output (C-13)	(2/26-4/16/79) After modification total ferrous output (C-13)
Bulk density	308.45 kg/m^3	315.60 kg/m^3
Sizing-mm	%	%
64	33.58	39.90
38	35.46	35.53
19	22.16	16.87
9.5	5.29	4.84
4.8	2.09	1.80
2.4	0.84	0.57
Fines	0.55	0.50
Composition	%	%
Cardboard	0.56	0.03
Other paper	0.83	0.40
Plastic	0.48	0.04
Wood	0.10	0.04
Glass	0.15	0.11
Ferrous	97.30	98.69
Nonferrous	0.00	0.01
Natural organic	0.14	0.01
Cloth	0.05	0.56
Tar	0.00	0.00
Miscellaneous	0.41	0.13

Output Reject Stream from ADS System

Table 45 gives the bulk density, sizing, and composition characteristics of the ADS reject output stream. As seen on the table, the bulk density decreased from 482.84 to 325.25 kg/m^3; material sizing increased in the 9 mm and larger classifications. Material smaller than 2 mm dropped from 17.93 to 1.90%.

In the reject stream, all composition classes except glass and miscellaneous increased. Glass dropped from 26.04 to 18.33%; and miscellaneous, from 35.54 to 22.19%.

COMPARISON OF FUEL CHARACTERISTICS

The mean and standard deviation results obtained for heating value, chloride, and proximate, ultimate, and elemental analyses are displayed in Table 46. The values are for 8 weeks of sampling, and the corresponding 8 weeks of the prior year are given.

The material fed to the ADS system is improved; heating value increased from 11,614.7 to 13,769.6 kJ/kg, and ash decreased from 20.08 to 12.75%. Elemental analysis expressed as a percentage of ash shows an increase in all constituents except nickel.

The ADS system heavies or rejects are also improved from the standpoint that they can be used as a fuel source in a mass burn incinerator. The heating value increased from 9,986.7 to 12,266.5 kJ/kg; the ash content decreased from 40.66 to 22.69%. Moisture increased somewhat from 15.60 to 21.50%, and the elemental ash analysis shows an increase in aluminum, copper, iron, and nickel, but a decrease in lead and zinc.

TABLE 45. ADS REJECTS COMPARISON BEFORE AND AFTER MODIFICATION - (8 Weeks Sampling)

	(2/24-4/20/78) Before modification ADS heavies rejects (C-15)	(2/26-4/16/79) After modification ADS heavies rejects (C-15)
Bulk density	482.84 kg/m^3	325.25 kg/m^3
Sizing-mm	%	%
64	1.48	7.47
38	9.93	11.47
19	24.53	34.30
9.5	22.64	31.47
4.8	14.28	10.33
2.4	9.26	3.09
Fines	17.93	1.90
Composition	%	%
Cardboard	0.94	4.05
Other paper	7.34	7.84
Plastic	5.73	8.83
Wood	11.91	14.28
Glass	26.04	18.33
Ferrous	1.19	1.18
Nonferrous	4.66	10.34
Natural organic	5.84	11.46
Cloth	0.10	0.63
Tar	0.75	0.91
Miscellaneous	35.54	22.19

TABLE 46. FUEL CHARACTERISTICS COMPARISON BEFORE AND AFTER MODIFICATION Before (2/24/78-4/18/78) - After (2/26/79-4/16/79)

	Second shredder discharge, S-9, C-6				RDF-Atlas bin inlet, S-9				ADS heavies, S-10, C-7			
	1978		1979		1978		1979		1978		1979	
	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
Higher heating value kJ/kg	11,614.7	663.6	13,769.6	1,219.7	11,408.7	406.5	14,209.1	829.4	9,986.7	709.2	12,266.5	923.8
Chloride (total) %					0.23	0.06	0.21	0.12				
Proximate analysis (%)												
Ash	20.08	3.44	12.75	5.29	20.99	2.52	9.55	1.17	40.66	5.65	22.69	7.89
Fixed carbon	-	-	-	-	30.79	3.04	56.10	5.99	-	-	-	-
Moisture	22.80	2.10	20.23	7.05	22.06	4.86	18.42	5.57	15.60	1.68	21.50	3.503
Volatile matter	-	-	-	-	26.16	3.12	15.93	2.39	-	-	-	-
Ultimate analysis[a] (%)												
Carbon (1)					28.45	2.45	36.67	11.82				
Hydrogen					6.85	0.65	7.42	0.87				
Nitrogen					0.39	0.08	0.34	0.06				
Oxygen					42.75	3.77	45.62	12.31				
Sulfur					0.34	0.10	0.19	0.06				
Ash					20.99	2.52	9.55	1.17				
Elemental analysis (% of ash)												
Aluminum[b]	4.34	0.60	6.15	1.44	3.63	0.74	8.77	2.63	2.88	0.55	3.98	2.21
Copper	0.06	0.01	0.09	0.04	0.27	0.55	0.14	0.12	0.16	0.08	0.20	0.31
Iron	2.19	0.28	2.43	0.32	2.69	0.34	3.36	1.95	2.11	0.68	2.92	1.96
Lead	0.21	0.11	0.59	0.72	0.26	0.15	0.22	0.08	0.48	0.61	0.34	0.42
Nickel	0.07	0.02	0.50	0.01	0.08	0.02	0.05	0.11	0.06	0.01	0.08	0.03
Zinc	0.29	0.15	0.42	0.14	0.24	0.12	0.47	0.18	0.36	0.23	0.30	0.18

[a] Hydrogen and oxygen contain that due to water vapor.

[b] Percentage expressed as element.

The RDF is also improved. Heating value is increased from 11,408.7 to 14,209.1 kJ/kg, and the chloride content is reduced from 0.23 to 0.21%. Ash is reduced from 20.99 to 9.55%; and moisture, from 22.06 to 18.42%. The fixed carbon content is increased from 30.79 to 56.10%. Volatiles are essentially free hydrocarbon; their decrease with a corresponding increase in fixed carbon indicates that the RDF is a more stable fuel from a storage standpoint.

The ultimate analysis shows that carbon is increased from 28.45 to 36.67%; hydrogen (including that associated with oxygen in water) is increased from 6.85 to 7.42%; and oxygen is increased slightly from 42.75 to 45.62%. The nitrogen content is reduced slightly from 0.39 to 0.34%, and the sulfur is reduced from 0.34 to 0.19%.

The elemental analysis of the ash indicates the aluminum increased from 3.63 to 8.77%; iron increased from 2.69 to 3.36%; and zinc increased from 0.34 to 0.47%. The copper content decreased from 0.27 to 0.14%; lead decreased from 0.26 to 0.22%; and nickel decreased from 0.08 to 0.05%.

ELECTRICAL ENERGY CONSUMPTION

The process plant modification increased the overall average energy consumption from 75.15 to 89.60 kWh/Mg. Table 47 lists the added electrical equipment. The primary and secondary shredder, as well as the Atlas storage bin, exhibited a fractional reduction in relative energy consumption, while the air classification blower, pneumatic transport blower, and the indirect equipment increased their relative consumption (see Table 48).

TABLE 47. MAJOR ELECTRICAL EQUIPMENT ADDED DURING OCTOBER-DECEMBER 1978 PLANT MODIFICATION

- Disc screen system
  - First disc screen two 5.6 kW (7-1/2 hp) motors (changed to one 30 kW (40 hp) motor with hydraulic drive in May 1979)
  - Second disc screen one 5.6 kW (7-1/2 hp) motor
  - Conveyors
    - First disc screen undersize flow
Conveyor C-3A one 7.5 kW (10 hp) motor
    - Second disc screen undersize flow
Conveyor C-5A one 3.7 kW (5 hp) motor and
Conveyor C-5B one 7.5 kW (10 hp) motor
  - Total added 54 kW (72.5 hp)
- Dust collection system
  - Main blower one 37.3 kW (50 hp) motor
  - Collection bag shakers four 1.1 kW (1-1/2 hp) motors
  - Collection bag air locks four 1.1 kW (1-1/2 hp) motors
  - Dust transport blower to dust collection cyclone one 7.5 kW (10 hp) motor
  - Total added 53.7 kW (72 hp)
- Ferrous removal at chute
  - Conveyor C-14A one 0.37 kW (1/2 hp) motor

TABLE 48. COMPARISON OF ELECTRICAL ENERGY CONSUMPTION

December-April	Primary shredder	Secondary shredder	ADS system	Pneumatic transport	Atlas storage bin	Indirect	kWh month	Average kWh/Mg
1976-77	8.09	13.59	5.83	4.61	17.04	50.85	239,158	74.72
1977-78	8.88	12.90	7.39	4.65	16.04	50.14	243,254	75.57
10 mo. avg.	8.49	13.24	6.61	4.63	16.54	50.49	241,206	75.15
1978-79[a]	7.82	10.44	7.99	5.61	15.10	53.04	229,222	89.60

[a] 78-79 is after process plant modifications.

The relatively large drop in secondary shredder energy (13.24 to 10.44%) would be attributable to the reduced mass flow through it, since only the scalping screen-shredded oversize now flows through it instead of the total shredder stream. There is an increase in the air classifier blower energy, because the ADS system operates at higher air flow rates and the blower discharges into the baghouse, which increases the discharge side pressure.

The increase in pneumatic transport blower energy may be due to the reduced air leakage through the air lock feeder, which results in higher pneumatic transport pressures. The indirect energy consumption increase is not expected as electrical equipment associated with the disc screen and dust collection systems was increased. This equipment requires the additional 14.45 kWh/Mg energy. The system tradeoff, then, is additional processing and cleanup versus improved product, cleaner equipment, and a less dusty work environment.

PROCESS PLANT LABOR ACTIVITIES

In Table 49, the labor activities of the 5 month period, December 1977 through April 1978, are compared with the corresponding period of 1978-1979 following plant modification. Activities are listed in order of decreasing fraction of labor on the basis of the 1977-1978 period. Comparing the total average labor hours per month shows essentially the same level of effort (2,469.10 versus 2,396.85 hr/month). Comparison on an hour-per-megagram basis yields 0.767 versus 0.937. The system processed 16,096 Mg during the 1977-1978 period and only 12,791 in the 1978-1979 period.

TABLE 49. LABOR ACTIVITY COMPARISON BEFORE AND AFTER PLANT MODIFICATION

Activities	Before December 77-April 78 (%)	After December 78-April 79 (%)
Cleaning process area	17.75	10.03
End loader operations	10.74	10.32
Tipping floor	9.48	8.42
Conveyors	8.91	17.00
Control room monitoring	6.64	9.99
Tours and secretarial	6.42	4.33
General maintenance	6.02	4.26
Operations and grates	5.18	5.72
Pneumatic transport system	4.87	0.69
Air classification system	3.91	5.19
Landfill	3.30	6.42
Rejects	3.15	5.51
Miscellaneous	2.52	1.16
Ferrous metals	2.33	1.02
Custodial	2.00	2,78
Non-ferrous system	1.99	0
Shredders	1.07	1.57
Dings magnet	0.96	0.11
Atlas storage bin	0.76	0.09
Shredder hammers	0.68	0.29
Paper baler	0.60	0.03
Fires	0.40	0.78
Wood chips	0.18	0
Electrical room	0.16	0.78
Disc screens	-	1.69
Sand and glass from disc screen	-	0.10
Dust control	-	1.73
Total percentage	100	100
Average hours per month	2,469.10	2,396.85

The overtime hours in the 1977-1978 5 month period average 152.1 hr/month, while in the 5 month period after modification the average monthly overtime increased to 360.8 hr. Since the total hours worked are essentially the same for the two periods, the difference in overtime must be due to the reduction in the number of part-time employees and a partial increase in full-time personnel as follows:

Monthly average, December-April	1977-1978	1978-1979
Full-time employees	8.2	10.8
Part-time employees	10.2	5.0
Regular hours	2,317.0	2,036.05
Overtime hours	152.10	360.80
Total hours	2,469.10	2,396.85

In addition, there may be greater flexibility in scheduling part-time employees when work is to be done on an emergency repair basis.

The fraction of labor spent cleaning the process plant dropped from 17.75 to 10.03%, which may be attributed to the dust collection system. The fraction of time spent on the conveyors, however, increased from 8.91 to 17.00%; this may be because three conveyors were added in the disc screen system and one to the ferrous. The conveyors associated with the disc screen system demand attention because they have a large slope, and there is a tendency for material to slide back, particularly on conveyors C-3 and C-3A, when the refuse is wet.

The pneumatic transport system showed a decrease from 4.87 to 0.69%, but this decrease was due to a very large labor expenditure in December 1977 when severe transport tube pluggages occurred and a section of line was replaced. (Twenty percent of December 1977 labor was spent on the transport system.) Omitting the 1977 value yields an average for the first 4 months of 1978 of 0.56%, which is somewhat lower than the after-modification value.

The labor expended at the landfill operations increased from 3.30 to 6.42%, which may partially be due to the increase in handling reject and glass grit materials resulting from the improved cleanup of the refuse fuel product. Handling of these reject materials increased the labor fraction from 3.15 to 5.51%. The handling of glass grit, which is the reject material from the disc screen system, averages 0.1% of the labor.

ADDITIONAL PROCESS PLANT INVESTMENT

The major additions and modifications to the process plant during the October through December 1978 period totaled $450,000. This money was provided by an authorization from the federal government through EPA. Therefore, this increased investment does not appear on the City of Ames funds flow for the system.

The loss of revenue from the landfill-diverted refuse can be considered an additional "hidden cost" of the shutdown in addition to the operating personnel labor, utilities, and materials consumed during the modification period. It is estimated that 5,700 Mg of refuse were lost during this period, and the resulting revenue loss would be $57,000 based on an average revenue of $10/Mg incoming refuse.

There are additional costs, such as the rapid fill rate of the landfill area, since only one-tenth of the incoming mass of refuse goes to the landfill when processing. This order of magnitude increase in fill rate correspondingly shortens the useful life of the landfill site. This type of a cost estimate tends to be subjective since estimates are needed of prospective disposal site land costs, as well as transportation cost increases to the new site.

SECTION 11

PROCESS PLANT EMISSION CHARACTERIZATION

As mentioned in Section 7, the particulate effluent from the ventilator ducts on the refuse plant and the particulate in the ambient air of the process plant were sampled by appropriate methods.

Table 50 is a summary of the particulate emission from the three roof ventilators in operation during this study. It should be noted that the emission levels were very low, and in fact were virtually invisible to any observers. However, over the 144 min sampling period, the sampling train filters collected particulate effluent in the amounts shown in Table 50.

TABLE 50. AMES REFUSE PROCESSING PLANT PARTICULATE EMISSIONS

EPA Run No.	Roof ventilator No. 1 (mg/std m^3)	Roof ventilator No. 2 (mg/std m^3)	Roof ventilator No. 3 (mg/std m^3)	Total	Roof ventilator No. 1 (g/sec)	Roof ventilator No. 2 (g/sec)	Roof ventilator No. 3 (g/sec)	Total
350	32.16	18.94	20.85	71.95	0.516	0.209	0.449	1.174
351	29.77	36.14	25.27	91.18	0.422	0.453	0.538	1.413
352	37.19	53.80	31.14	122.13	0.518	0.629	0.632	1.779
353	23.26	31.35	9.798	64.41	0.343	0.368	0.201	0.912
Average				87.42				1.320
Standard deviation				±25.74				±0.368

The refuse plant ambient air samples were taken at the locations shown in Figure 50. Two ambient air samples were taken from each of three levels

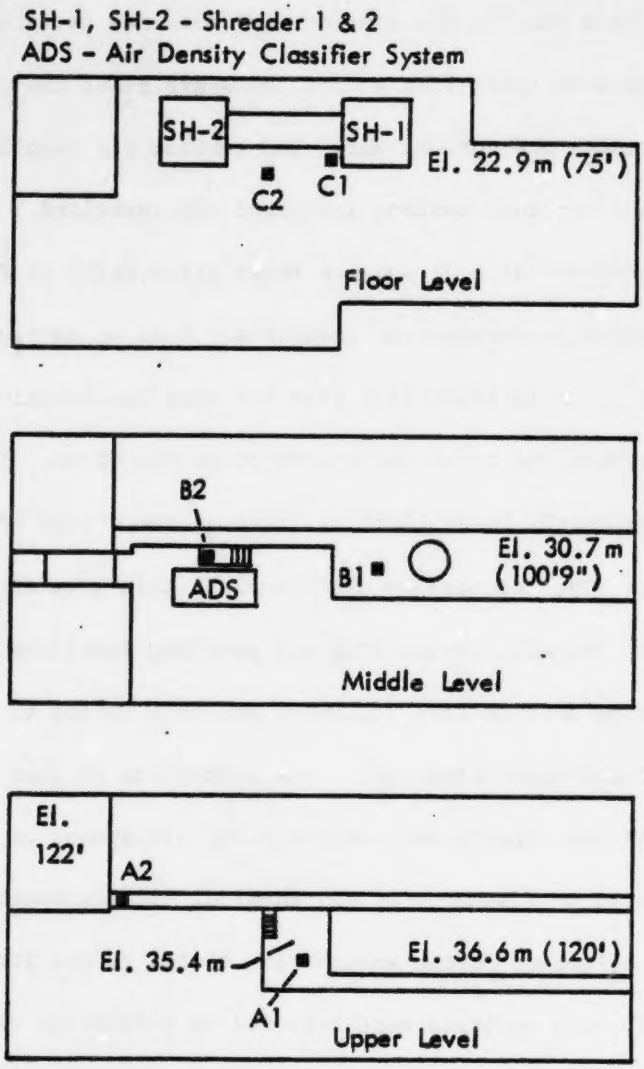
SH-1, SH-2 - Shredder 1 & 2
ADS - Air Density Classifier System
SH-2
SH-1
C2
C1
El. 22.9 m (75')
Floor Level
B2
ADS
B1
El. 30.7 m
(100'9")
Middle Level
El.
122'
A2
El. 35.4 m
A1
El. 36.6 m (120')
Upper Level

Figure 50. Processing plant sampling locations.

in the refuse processing plant (A, B, and C, as shown in this figure). The data were replicated for statistical purposes by sampling on different days such that from four to six samples were obtained at each sampling location. All samples were taken from a location where plant employees would typically work or breathe the ambient air. The ambient air sampling was performed before and after dust control equipment was installed. Measurement averages are tabulated in Table 51 and are shown graphically in Figure 51.

The dramatic decrease in ambient air dust or particulate is evident in Figure 51. This is especially true for sampling location C-2, which was located between the first and second stage shredders. This location was also approximately 10 to 15 ft in front of the bottom of the air density classifier. The decrease in dust level at this location was by a factor of nearly 20. Overall, considering all sampling locations, the decrease in dust levels due to dust control equipment was by a factor of 4.5. For persons working in the plant atmosphere, the perception is that the decrease in dust levels was significant and the plant atmosphere is much cleaner.

Table 52 is a summary of the chemical element constituency of the dust particles collected in the ambient air of the refuse processing plant. The samples for this analysis were obtained on chemically clean quartz fiber filters. The filters were loaded to varying extents with loose, fluffy, fibrous material and more solid particulates. The loose material was brushed from the filter and bottled, and a 25 mm diameter disc of the remaining filter was removed for analysis.

TABLE 51. AMES REFUSE PROCESSING PLANT AMBIENT AIR PARTICULATE

	Before dust control mg/m^3			After dust control mg/m^3		
	$\bar{x}$	n	σ	$\bar{x}$	n	σ
Overall	6.858	24	6.301	1.516	35	1.508
Level A	5.609	8	2.544	1.240	11	1.061
Level B	5.501	8	2.720	2.326	12	2.128
Level C	9.461	8	10.239	0.958	12	0.430
Location A1	6.529	4	2.419	0.865	5	0.231
Location A2	4.690	4	2.645	1.553	6	1.244
Location B1	5.376	4	0.999	3.791	6	1.827
Location B2	5.626	4	4.028	0.862	6	0.611
Location C1	1.669	4	0.840	0.122	6	0.339
Location C2	17.253	4	9.056	0.793	6	0.313

$\bar{x}$ = average

n = number of samples

σ = standard deviation

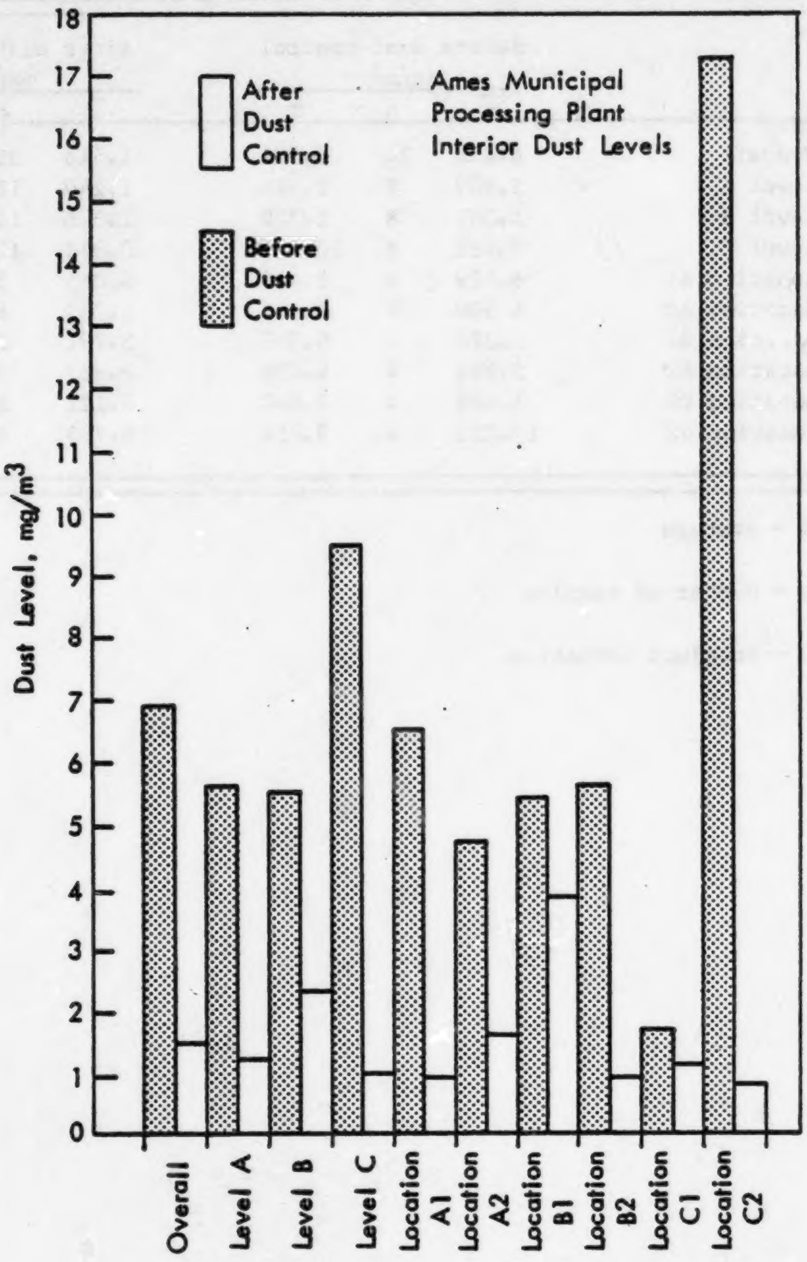

Figure 51. Particulate levels inside the processing plant before and after installation of a dust control system.

TABLE 52. CHEMICAL ELEMENT CONSTITUENCY OF THE REFUSE PROCESSING PLANT AMBIENT PARTICULATES

Element[a]	On filter[a] (μg)	Loose[a] (μg)	Total[a] (μg)	Concentration[a] ($\mu g/m^3$)
Ag	397	NA[b]	397[c]	17.7[c]
Al	NA	407	407	18.2[c]
As	75	7	82	3.66
Ba	397	15	412	18.4
Br	15	NA	15[c]	0.67[c]
Ca	1,750	2,321	4,071	181
Cd	150	1	151	6.74
Cl	105	NA	105	4.69[c]
Co	NA	1	1[c]	0.04[c]
Cr	35	4	39	1.74
Cu	8	8	16	0.71
Fe	1,033	792	1,825	81.3
Ga	30	NA	30[c]	1.34[c]
Ge	30	2	32	1.43
Hg	NA	3	3[c]	0.13[c]
K	170	NA	170	7.59[c]
Mg	NA	352	352[c]	15.7[c]
Mn	44	23	67	2.99
Ni	20	3	23	1.03
Pb	89	96	185	8.26
Rb	8	NA	8[c]	0.36[c]
Sb	150	3	153	6.83
Se	15	6	21	0.94
Si	Major	Major	Major	
Sn	145	NA	145[c]	6.47[c]
Sr	8	NA	8[c]	0.36[c]
Ti	5	NA	85[c]	3.79[c]
Tl	NA	3	3[c]	0.13[c]
V	75	3	78	3.48
Zn	76	82	158	7.05
Total	50,030	129,670	179,700	8,023

[a] Values in this table are an average of the material collected at the six different locations in the refuse processing plant during a single day of sampling shown in Figure 18. These data were obtained before the dust control system was installed. Thus, the values listed would represent the maximum possible amount of dust and concentration. Following installation of the dust control system, the concentration levels of dust in the plant dropped by a factor of 4.5 on the average based on the amount of material collected with ambient air high volume samplers.

[b] NA means either not analyzed or below the analytical instrument detection limit.

[c] Indicates numbers are actually slightly larger than stated.

The loose material was dissolved by being heated in a mixture of HNO_3 and $HClO_4$. A Bethge digestion apparatus was used to prevent the loss of volatile elements or compounds. The procedure resulted in two separate solutions, one containing $HClO_4$ and nearly all of the inorganic constituents, and the other containing HNO_3 and any volatile inorganic constituents. These two acid solutions were then analyzed for 20 elements by the inductively coupled plasma-atomic emission spectroscopy technique. The combined analyses are listed in the middle column of Table 52.

SECTION 12

POWER PLANT EMISSION CHARACTERIZATION

BOILER CONDITIONS AND FUEL AND BOTTOM ASH CHARACTERISTICS

Most of the results are reported in a data matrix format that indicates the control factor of load and percent RDF in the experimental runs on unit No. 7. For each load and each percent of RDF used, three experimental runs were accomplished. The average of the results for each of the three runs, as well as the standard deviations, are tabulated as a cell average and cell standard deviation in the tables presented in this section. Each data point on the plots included in this section is a cell average representing the average of three experimental runs unless otherwise noted. It should also be noted that two standard deviations on each side of the cell average would approximately correspond to the 95% statistical confidence band.

Curves and lines drawn through the data points on the plots are meant to show general trends in the data. They do not imply any particular mathematical expression which may (or may not) govern the behavior of a particular measured variable.

Air, Feedwater, and Steam Characteristics for the Experimental Runs

Table 53 includes the average air, feedwater, and steam characteristics for the experimental runs performed on steam generator unit No. 7. Both

TABLE 53. AVERAGE AIR, FEEDWATER, AND STEAM CHARACTERISTICS FOR TESTS ON BOILER UNIT NO. 7

Nominal turbine load (%)	RDF (%)	Year		Steam load[a] (%)	RDF heat input (%)	Air wet bulb °C	Dry bulb °C	Rel. hum. (%)	Bar. pres. kPa	Feed-water temp. °C	Steam temp. °C	Steam pres. kPa	Stack flow CMS_{stp}	Stack temp. °K	Stack pres. kPa
60	0	1976	x̄[b]	45.4	0.00	12.0	5.	33.	97.20	181.	479.	5867.	30.08	434.	96.89
			σ	1.9	0.00	6.6	5.	1.	0.44	1.	2.	4.	0.22	4.	0.45
80	0	1976	x̄	65.2	0.00	3.0	-1.	47.	97.80	195.	476.	5888.	37.62	441.	97.40
			σ	.7	0.00	5.0	4.	10.	0.78	2.	2.	18.	2.85	9.	0.76
80	0	1978	x̄	64.7	0.00	22.0	28.	60.	97.68	197.	476.	6048.	38.79	454.	97.06
			σ	1.6	0.00	5.0	4.	8.	0.58	2.	2.	145.	2.31	4.	0.57
80	10	1978	x̄	65.3	12.72	19.0	23.	69.	98.09	196.	477.	6151.	37.76	468.	97.46
			σ	0.5	1.43	3.0	2.	17.	0.44	1.	1.	21.	0.59	3.	0.46
80	20	1978	x̄	63.8	18.96	18.0	23.	57.	98.09	194.	476.	6034.	37.91	481.	97.47
			σ	0.8	5.27	2.0	5.	12.	0.30	1.	1.	152.	0.38	4.	0.29
100	0	1976	x̄	86.7	0.00	-4.0	-7.	43.	98.00	206.	480.	5929.	50.75	453.	97.68
			σ	1.5	0.00	11.0	9.	3.	0.75	2.	1.	17.	0.18	7.	0.61
100	0	1978	x̄	88.5	0.00	23.0	28.	62.	97.68	209.	486.	5896.	45.44	469.	97.34
			σ	1.3	0.00	3.0	3.	6.	0.58	1.	2.	34.	0.96	5.	0.44
100	10	1977	x̄	88.6	10.07	21.0	15.	53.	98.00	209.	477.	5895.	41.96	449.	97.38
			σ	1.6	0.17	1.0	2.	10.	0.00	2.	2.	0.	11.15	4.	0.01
100	10	1978	x̄	86.9	13.52	22.0	27.	64.	97.92	209.	479.	5917.	42.92	468.	97.33
			σ	1.2	1.95	2.0	2.	10.	0.14	2.	3.	41.	2.34	6.	0.10
100	20	1978	x̄	88.6	20.80	23.0	28.	62.	97.68	209.	485.	6234.	43.53	479.	97.11
			σ	1.6	1.18	3.0	3.	9.	0.20	2.	4.	48.	1.59	13.	0.18

[a] Re 163,600 kg steam/hr.

[b] x̄ and σ represent the mean and the standard deviation, respectively.

the average and standard deviations are given for each cell, where each cell represents a given nominal turbine load and a given percent of RDF input on a heat energy basis. From this table it can be observed that the steam load is also tabulated on a percent basis which corresponds approximately to a given percent turbine load. The actual RDF heat energy input tabulated shows some slight variation from the nominal values desired for the test set-up. The variation in the amount of heat energy input is indicative of the amount of control of that particular variable during the operation of unit No. 7.

The characterization of the air entering the boiler unit for combustion purposes is given by wet and dry bulb measurements. They are used to determine the relative humidity of the air entering the boiler. The barometric pressure of the air at the turbine location, the feedwater temperature, and the pressure and temperature of the steam generated in the boiler unit for use in the turbine are also tabulated. The flue gas or combustion products being exhausted from the boiler into the stack are given in terms of flow rate, temperature, and pressure as measured at the sampling location in the smokestack.

Characteristics of Input Fuels

The average of heating values, ultimate analysis, and trace elements analysis for both coal and RDF used during the tests on unit No. 7 are listed in Table 54. It should be noted that the ash content of the RDF is higher than that of the coal used during 1978, and that both the heating

TABLE 54. MEAN VALUES OF COAL AND RDF CHARACTERISTICS AS FIRED

Quantity	Coal				RDF	
	1976		1978		1978	
	Mean ($\bar{x}$)	Std dev (σ)	Mean ($\bar{x}$)	Std dev (σ)	Mean ($\bar{x}$)	Std dev (σ)
Number of samples	14		18		12	
Heating value (HHV)	22.42	0.13	23.6	0.52	13.02	0.83
kJ/g (Btu/lb)	(9,648)	(57)	(10,156)	(224)	(5,602)	(359)
Moisture (%)	16.67	3.91	16.6	1.2	24.04	3.06
Ash (%)	12.98	2.30	9.74	2.23	13.09	2.72
Carbon (%)	53.96	2.81	56.6	1.5	30.66	2.92
Hydrogen (%)	3.42	0.65	4.01	0.19	4.31	0.44
Sulfur (%)	3.27	0.85	2.79	0.81	0.32	0.06
Chlorine (%)	0.03	0.01	0.21	0.12	0.35	0.15
Oxygen (%)	9.66	1.52	9.08	2.26	27.04	2.87
Trace elements[a]						
Aluminum (%)	1.33	0.23	1.29	0.17	1.36	0.48
Antimony	BDL[b]		BDL		25	17
Arsenic	<3.0	1.5	<5.1	0.5	<16	3
Barium	BDL		246	61	264	125
Beryllium[c]			37	12	BDL	
Bromine	BDL		4.2	3.0	23	19
Cadmium	BDL		BDL		6.4	8.1
Calcium (%)	1.22	0.17	0.77	0.30	1.49	0.31
Chlorine (%)	BDL		0.09	0.02	0.22	0.16
Chromium	BDL	4	19	7	34	8
Copper		2	15	2	572	854
Gallium	2.8	0.4	2.5	0.5	16	3
Germanium	8.0	3.3	5.3	0.9	1.7	0.3
Iron (%)	1.42	0.18	1.55	0.35	0.42	0.08
Lead	65	19	36	13	613	289
Manganese	91	12	76	23	194	47
Mercury	BDL		BDL		BDL	
Nickel	74	6	18	5	14	4
Potassium (%)	0.14	0.05	0.09	0.02	0.32	0.07
Rubidium	6.1	3.2	4.8	1.0	11.1	5.7
Selenium	<2	0	<2	0	<8	1
Silicon (%)	2.32	0.38	1.94	0.25	2.92	0.61
Silver	BDL		BDL		5.4	6.5
Strontium	74	35	86	28	46	11
Sulfur (%)	3.04	0.57	2.94	0.76	0.38	0.10
Tin	BDL		20	5	27	8
Titanium	<622	46	540	40	1,925	441
Vanadium	79	17	83	16	154	32
Yttrium	BDL		6.0	1.3	BDL	BDL
Zinc	61	40	66	41	762	345
Zirconium	BDL		15	4	23	5

[a] Values are in ppm except where indicated.

[b] BDL: Below Detection Limit.

[c] Beryllium not available for 1976 data.

values and the amount of sulfur in the RDF is lower than that of the coal for the comparison runs made during this study. The significance of these observations is that, as the amount of refuse used in the boiler unit is increased, an increased amount of ash will be generated due to using refuse. The additional amount of ash was expected to show up partially as fly ash and partially as bottom ash. Consequently, as the RDF increased, the amount of particulate emissions was expected to increase. This was also in agreement with the previous data obtained on traveling grate stoker unit Nos. 5 and 6 during 1976 and 1977.[1,10,17]

Because the sulfur content of the RDF was lower than in the coal, it was also expected that the oxides of sulfur emitted from the smokestack would decrease significantly with increases in RDF.

Based on the tabulation of trace elements from the fuel samples, it is evident that the RDF contains significantly more copper, lead, titanium, and zinc than coal used as a fuel. As a consequence, the emissions of these four elements were expected to increase significantly. The most important of the three elements would be the lead because of its toxic nature. Because of this concern, some additional ambient air sampling was performed on a random basis during the 1978 experiments. Germanium, iron, and sulfur are found in smaller concentrations in the RDF than in the coal, but there does not appear to be a significant difference between RDF and coal in the relative amounts of the other elements.

Characteristics of Bottom and Fly Ash

Tables 55 and 56 are tabulations of the combustible and noncombustible constituents of the bottom ash and fly ash, respectively, from unit No. 7. The interesting feature of these data is that the characterizations of fly ash and bottom ash in terms of mineral matter and carbon are significantly different when coal is the only fuel burned in the boiler. However, as the fuel mixture changes from 0 to 20% RDF, the characteristics of the fly ash and bottom ash become nearly identical. Another feature of the data in Tables 55 and 56 is that tabulations are given for the operation of unit No. 7 both before and after the bottom dump grates were installed. A comparison of these data shows that the bottom grates were highly significant in retaining unburned combustible material in the furnace region so that the combustible portion of the RDF could continue to burn once it had fallen through the suspension zone to the grate of the boiler. Thus, the dump grates were instrumental in helping derive the available heat energy from the fractions of RDF that fell through the suspension zone of the boiler before complete combustion had occurred. Before the installation of the dump grates, for example, with 10% RDF at 100% load, as much as 35.4% carbon was dropping to the bottom pit of the boiler and being lost to the system. After the installation of the dump grates, the loss of carbon amounted to about 1.5%. A similar trend shows up for the carbon in the fly ash, but the degree of loss is much less than with the bottom ash.

TABLE 55. ANALYSIS OF BOTTOM ASH FROM BOILER UNIT NO. 7

Prior to installation of dump grates; 1976, 1977

Parameter (%)	60% Load	80% Load	100% Load	
	0% RDF	0% RDF	0% RDF	10% RDF
Carbon	7.51 (4.90)a/	5.46 (1.24)	5.53 (0.95)	35.4 (3.42)
Hydrogen	0.87 (0.56)	0.61 (0.20)	0.49 (0.15)	3.83 (0.55)
Sulfur	2.58 (1.12)	3.59 (1.40)	2.90 (3.93)	0.75 (0.06)
Chlorine	0.01 (0.01)	0.00 (0.00)	0.00 (0.01)	0.18 (0.04)
Mineral	89.0 (4.33)	90.3 (0.98)	91.1 (4.76)	59.9 (4.06)

After installation of dump grates; 1978

Parameter (%)	80% Load			100% Load		
	0%	10% RDF	20% RDF	0% RDF	10% RDF	20% RDF
Carbon	4.66 (0.88)	2.10 (0.28)	3.11 (0.72)	6.62	1.49 (0.27)	1.85 (1.21)
Hydrogen	0.20 (0.07)	0.23 (0.02)	0.37 (0.08)	0.38	0.18 (0.04)	0.21 (0.12)
Sulfur	1.07 (0.87)	1.12 (0.99)	0.31 (0.04)	8.98	1.12 (0.71)	0.23 (0.01)
Chlorine	0.01 (0.00)	0.02 (0.01)	0.02 (0.02)	0.03	0.02 (0.01)	0.02 (0.01)
Mineral	94.8 (0.82)	96.6 (0.82)	96.2 (0.80)	84.0	97.2 (0.51)	97.7 (1.41)

a/ Values in parantheses are ± one standard deviation.

TABLE 56. ANALYSIS OF FLY ASH FROM BOILER UNIT NO. 7

Prior to installation of dump grate 1976, 1977

Parameter	60% Load		80% Load		100% Load			
(%)	0% RDF		0% RDF		0% RDF		10% RDF	
Carbon	0.79	(0.19)[a]	0.95	(0.27)	1.87	(1.15)	4.68	(0.43)
Hydrogen	0.27	(0.08)	0.60	(0.25)	0.61	(0.28)	0.07	(0.02)
Sulfur	1.52	(0.25)	1.35	(0.28)	1.35	(0.18)	1.02	(0.12)
Chlorine	0.00	(0.00)	0.00	(0.00)	0.01	(0.02)	0.00	(0.00)
Mineral	97.4	(0.47)	97.1	(0.57)	96.2	(1.47)	94.2	(0.57)

After installation of dump grate, 1978

Parameter	80% Load						100% Load					
(%)	0% RDF		10% RDF		20% RDF		0% RDF		10% RDF		20% RDF	
Carbon	1.85	(0.55)	2.43	(0.35)	2.54	(0.05)	1.92	(0.78)	2.41	(0.49)	2.40	(0.40)
Hydrogen	0.10	(0.02)	0.11	(0.01)	0.17	(0.05)	0.10	(0.02)	0.11	(0.01)	0.11	(0.02)
Sulfur	0.70	(0.34)	0.69	(0.13)	0.86	(0.14)	1.02	(0.51)	0.82	(0.21)	0.83	(0.13)
Chlorine	0.01	(0.01)	0.01	(0.00)	0.03	(0.01)	0.01	(0.01)	0.02	(0.01)	0.02	(0.01)
Mineral	97.3	(0.55)	96.8	(0.46)	96.4	(0.09)	97.0	(0.39)	96.6	(0.59)	96.6	(0.30)

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[a] Values in parentheses are ± one standard deviation.

Another interesting feature of the data is that the mineral ash content of both the bottom and fly ash became more nearly the same (on the order of 97%) following installation of the dump grates. Prior to the dump grate installation, the percentage of mineral content in the bottom ash was significantly lower, mainly because of the additional carbon remaining in the RDF which had dropped into the bottom hopper of the boiler.

Tables 57 and 58 are tabulations of the trace elements in the bottom ash and fly ash, respectively, both before and after installation of the dump grates. Twenty-eight different elements were scanned in both the bottom ash and fly ash by means of x-ray fluorescence (XRF). The tables show the cell averages and cell standard deviations for three experimental runs for a given boiler load and a given amount of RDF fed to the boiler. These tables are presented so that a comparison can be made with the trace elements scanned in the input fuels. If mass balances are desired, the quantity coming in with the input fuel minus the amount of the individual trace element in the bottom ash minus the amount of the individual amount in the fly ash collected in the ESP hopper would give an estimate of the amount of the element leaving the smokestack of the boiler. Trace elements were also analyzed from the particulates collected in the smokestack and from sampling train impinger solutions to yield estimates of the trace elements that are emitted from the boiler stack. However, these estimates are not as reliable as those found by taking what comes in with the input fuel and subtracting what drops out with the bottom grate ash and the hopper fly ash.

TABLE 57. TRACE ELEMENT ANALYSIS OF BOTTOM ASH FROM BOILER UNIT NO. 7

Parameter (ppm except where noted)	After installation of dump grates a/										
	80% Load						100% Load				
	0% RDF		10% RDF		20% RDF		0% RDF	10% RDF		20% RDF	
Al (%)	7.43	(247) b/	6.18	(0.60)	5.43	(0.43)	3.80	5.23	(0.21)	5.40	(0.92)
Si (%)	14.7	(1.5)	21.0	(2.9)	20.8	(1.3)	11.0	24.3	(1.5)	24.7	(2.3)
S (%)	0.92	(0.49)	0.64	(0.41)	0.27	(0.10)	4.80	0.67	(0.24)	0.5	(0.0)
Cl (%)	0.1	(0.0)	0.1	(0.0)	0.1	(0.0)	0.3	0.3	(0.0)	0.3	(0.0)
K (%)	0.75	(0.08)	0.87	(0.03)	0.85	(0.02)	0.45	0.83	(0.02)	0.95	(0.02)
Ca (%)	7.44	(3.40)	7.59	(0.77)	7.88	(1.02)	14.10	7.22	(0.27)	7.88	(0.21)
Ti (%)	0.48	(0.07)	0.57	(0.11)	0.52	(0.05)	0.16	0.42	(0.02)	0.46	(0.06)
V	467	(175)	536	(89)	524	(34)	210	520	(24)	520	(52)
Cr	168	(79)	266	(90)	311	(53)	890	1,108	(116)	1,217	(1,109)
Mn	990	(215)	960	(218)	880	(143)	1,000	973	(41)	1,020	(128)
Fe (%)	17.4	(1.7)	8.9	(3.0)	6.1	(1.9)	13.8	7.3	(0.9)	7.3	(0.5)
Ni	103	(26)	80	(23)	57	(6)	230	283	(39)	337	(293)
Cu	66	(7)	500	(332)	498	(125)	130	530	(39)	610	(10)
Zn	717	(131)	1,275	(201)	1,660	(387)	160	998	(78)	1,047	(81)
Ga	11.0	(1.7)	36.8	(8.1)	41.8	(4.0)	10	28.3	(5.2)	25.3	(2.1)
Ge	15.0	(4.4)	11.0	(1.4)	10.0	(0.0)	10	10	(0)	10	(0)
As	50	(0)	50	(0)	50	(0)	10	10	(0)	10	(0)
Se	5	(0)	5.3	(0)	5	(0)	5	5	(0)	5	(0)
Br	12.3	(12.7)	5	(0)	5	(0)	5	10.6	(8.3)	14	(16)
Rb	27.7	(3.8)	27.0	(2.7)	24.5	(2.1)	11.0	31.0	(3.7)	32.0	(1.7)
Sr	567	(180)	414	(84)	424	(83)	260	356	(5)	387	(55)
Ag	0.47	(0.06)	1.05	(0.44)	4.68	(1.25)	1	2.23	(0.46)	3.73	(2.94)
Cd	0.87	(0.50)	0.93	(0.85)	1.73	(1.14)	1	1.00	(0.01)	2.40	(1.85)
Sn	4.6	(3.8)	43.5	(25.3)	52.5	(11.6)	1.6	71	(59)	41	(6)
Sb	3.6	(4.5)	47.5	(16.2)	82.8	(26.1)	1	140	(61)	130	(53)
Ba	1,227	(462)	1,488	(125)	1,680	(173)	660	1,493	(104)	1,500	(62)
Pb	119	(53)	895	(319)	970	(123)	175	875	(97)	608	(81)
Hg	BDL		BDL		BDL		BDL	BDL		BDL	

a/ No analysis was performed on the bottom ash prior to the dump grate installation.

b/ Values in parentheses are ± one standard deviation.

TABLE 58. TRACE ELEMENT ANALYSIS OF FLY ASH FROM BOILER UNIT NO. 7

Prior to installation of dump grates; 1976, 1977

Parameter (ppm)	60% Load	80% Load	100% Load	
	0% RDF	0% RDF	0% RDF	10% RDF
Al (%)	9.00 (0.60)	8.70 (0.60)	8.80 (0.60)	7.40 (2.80)
Si (%)	15.3 (1.30)	14.8 (0.80)	14.8 (0.70)	13.5 (3.90)
S (%)	1.40 (0.10)	1.30 (0.40)	1.50 (0.10)	0.70 (0.60)
Cl (%)	N.A.	N.A.	N.A.	
K (%)	1.04 (0.15)	1.08 (0.08)	1.51 (0.11)	1.04 (0.00)
Ca (%)	9.90 (0.40)	1.04 (0.05)	11.6 (0.60)	7.10 (1.50)
Ti (%)	<0.53 (0.06)	<0.51 (0.08)	<0.45 (0.04)	0.56 (0.02)
V (%)	<957. (268.)	<925. (264.)	<653. (100.)	408. (470.)
Cr	175. (56.0)	149. (13.0)	148. (8.00)	183. (39.0)
Mn	657. (46.0)	743. (62.0)	897. (99.0)	805. (78.0)
Fe (%)	11.9 (0.10)	11.4 (1.10)	11.4 (0.60)	14.6 (1.50)
Ni	74.0 (16.0)	72.0 (20.0)	130. (17.0)	83.0 (24.0)
Cu	61.0 (10.0)	72.0 (24.0)	65.0 (14.0)	73.0 (4.00)
Zn	927. (386.)	813. (479.)	557. (55.0)	1080 (269.)
Ga	23.0 (4.00)	24.0 (8.00)	22.0 (4.00)	32.0 (1.00)
Ge	43.0 (4.00)	49.0 (4.00)	81.0 (17.0)	41.0 (9.00)
As	<29.0 (15.0)	<21.0 (1.00)	<20.0 (0.00)	<10.0 (0.00)
Se	<10.0 (0.00)	<9.00 (3.00)	<10.0 (0.00)	<5.00 (0.00)
Br	N.A.	N.A.	N.A.	N.A.
Rb	40.0 (5.00)	47.0 (9.00)	61.0 (6.00)	41.0 (3.00)
Sr	743. (234.)	640. (292.)	367. (95.0)	430. (127.)
Ag	N.A.	N.A.	N.A.	N.A.
Cd	N.A.	N.A.	N.A.	N.A.
Sn	N.A.	N.A.	N.A.	N.A.
Sb	N.A.	N.A.	N.A.	N.A.
Ba	N.A.	N.A.	N.A.	N.A.
Pb	148. (13.0)	158. (30.0)	177. (31.0)	510. (71.0)

(continued)

TABLE 58. (continued)

After installation of dump grates; 1978

Parameter (ppm)	80% Load 0% RDF		80% Load 10% RDF		80% Load 20% RDF		100% Load 0% RDF		100% Load 10% RDF		100% Load 20% RDF	
Al (%)	8.60	(1.50)	9.40	(0.80)	8.10	(1.40)	8.50	(2.30)	9.20	(1.30)	8.70	(1.90)
Si (%)	15.7	(1.00)	17.3	(0.80)	16.1	(1.90)	16.5	(2.40)	17.5	(2.70)	17.3	(2.90)
S (%)	0.95	(0.20)	0.65	(0.12)	0.84	(0.15)	1.11	(0.71)	0.85	(0.26)	0.84	(0.09)
Cl (%)	<0.30	(0.00)	<0.30	(0.00)	<0.30	(0.00)	<0.30	(0.00)	<0.30	(0.00)	<0.30	(0.00)
K (%)	0.96	(0.13)	1.23	(0.06)	1.16	(0.10)	0.95	(0.17)	1.16	(0.08)	1.29	(0.02)
Ca (%)	6.60	(3.30)	5.60	(0.70)	7.30	(1.40)	10.2	(3.70)	7.80	(1.20)	9.60	(0.30)
Ti (%)	0.59	(0.08)	0.71	(0.07)	0.65	(0.08)	0.53	(0.11)	0.71	(0.05)	0.63	(0.05)
V (%)	<753.	(156.)	<937.	(90.0)	<807.	(144.)	<654.	(266.)	<866.	(82.0)	<775.	(87.0)
Cr	260.	(19.0)	317.	(76.0)	243.	(81.0)	220.	(22.0)	223.	(18.0)	212.	(53.0)
Mn	861.	(137.)	930.	(232.)	1017	(104.)	967.	(208.)	1068	(239.)	986.	(78.0)
Fe (%)	17.6	(2.90)	13.9	(2.60)	15.0	(4.40)	14.9	(2.80)	11.1	(3.10)	11.8	(1.90)
Ni	116.	(21.0)	95.0	(1.00)	84.0	(6.00)	84.0	(9.00)	80.0	(16.0)	69.0	(10.0)
Cu	74.3	(9.70)	156.	(37.0)	131.	(19.0)	80.0	(27.0)	163.	(58.0)	126.	(11.0)
Zn	996.	(122.)	1590	(69.0)	1810	(382.)	379.	(118.)	1560	(393.)	1423	(178.)
Ga	26.7	(6.10)	<63.0	(20.0)	<58.0	(2.00)	24.0	(7.00)	<63.0	(13.0)	<51.0	(6.00)
Ge	43.7	(0.60)	37.3	(9.50)	28.0	(6.60)	44.7	(5.50)	30.3	(8.30)	34.7	(6.50)
As	<20.0	(0.00)	<20.0	(0.00)	<20.0	(0.00)	<20.0	(0.00)	<20.0	(0.00)	<20.0	(0.00)
Se	<20.0	(0.00)	<20.0	(0.00)	<20.0	(0.00)	<20.0	(0.00)	<20.0	(0.00)	<20.0	(0.00)
Br	<5.00	(0.00	<5.00	(0.00)	<5.00	(0.00)	<5.00	(0.00)	<5.00	(0.00)	<5.00	(0.00)
Rb	42.7	(2.90)	47.7	(6.50)	36.7	(2.50)	43.0	(4.00)	39.0	(5.60)	38.7	(3.50)
Sr	673.	(126.)	674.	(108.)	720.	(171.)	647.	(454.)	697.	(243.)	675.	(139.)
Ag	<0.70	(0.00)	2.50	(1.70)	6.20	(0.80)	<0.70	(0.00)	6.60	(3.30)	3.80	(1.40)
Cd	1.83	(1.17)	6.83	(1.26)	8.97	(2.70)	<0.70	(0.00)	7.17	(2.30)	5.20	(1.05)
Sn	4.90	(4.00)	28.3	(5.50)	35.7	(3.80)	3.60	(0.80)	47.0	(17.4)	34.0	(2.00)
Sb	4.10	(6.00)	29.7	(7.80)	54.0	(9.60)	20.7	(0.00)	83.0	(9.00)	53.0	(18.7)
Ba	1176	(297.)	1360	(223.)	1320	(278.)	1185	(878.)	1450	(373.)	1273	(254.)
Pb	241.	(140.)	907.	(180.)	1200	(87.0)	269.	(60.0)	1353	(313.)	913.	(147.)

Further analysis of the samples of RDF indicated that the ash fusion temperatures were from 60 to 100°C lower than those for coal. The RDF also has a high sodium content, which has a significant detrimental effect on the fouling index as compared to burning coal only. Thus, some difficulty with slagging and fouling was anticipated and was observed during these tests. The specific data on the fouling index and the ash fusion temperatures are contained in Section 15 of this report.

STACK EMISSIONS

Emission test results for the major effluents of interest are presented in Table 59. Each number represents the average of three independent runs unless otherwise noted. The standard deviations are also given (values in parentheses).

Particulates

The variations of the uncontrolled particulates, controlled particulates, and ESP efficiency with RDF are shown in Figures 52 through 54, respectively. From Figure 52 it can be observed that the uncontrolled emissions generally increase with RDF except for the 100% load data using coal only. Otherwise all the runs show significant increases in particulate emissions as the amount of RDF increases. It is also apparent from this plot that the initial data obtained using coal only on this boiler in 1976 and 1977 indicate a reverse trend in terms of particulate emissions. The expected particulate would be higher at 100% load than at 60% load as was the case for the 1978 data.

TABLE 59. SUMMARY OF SELECTED EMISSIONS FROM BOILER UNIT NO. 7

Prior to installation of dump grates; 1976, 1977

Parameter	(Units)	60% Load	80% Load	100% Load	
		0% RDF	0% RDF	0% RDF	10% RDF
Particulates (controlled)	(g/MJ)	0.10 (0.03)	0.15 (0.05)	0.26 (0.04)	0.23 (0.05)
Particulates (uncontrolled)	(g/MJ)	3.89 (0.44)	3.22 (0.74)	3.55 (0.02)	3.59 (0.13)
Oxides of sulfur, SO_x	(g/MJ)	1.12 (0.17)	1.24 (0.30)	1.59 (0.07)	1.24 (0.49)
Oxides of nitrogen, NO_x	(ng/J)	139. (15.0)	110. (38.0)	150. (9.00)	116. (18.0)
Chlorides	(ng/J)	2.21 (1.61)	5.86 (3.62)	12.1 (2.97)	3.29 (2.17)
Formaldehyde	(ng/J)	1.96 (2.40)	8.99 (18.9)	2.36 (1.97)	25.8 (22.6)
Methane	(ng/J)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)

After installation of dump grates; 1978

Parameter	(Units)	80% Load			100% Load		
		0% RDF	10% RDF	20% RDF	0% RDF	10% RDF	20% RDF
Particulates (controlled)	(g/MJ)	0.09 (0.02)	0.16 (0.04)	0.16 (0.03)	0.18 (0.09)	0.19 (0.03)	0.23 (0.04)
Particulates (uncontrolled)	(g/MJ)	2.81 (0.57)	3.28 (0.27)	3.53 (0.52)	3.41 (1.54)	3.13 (0.23)	3.21 (0.23)
Oxides of sulfur, SO_x	(g/MJ)	1.47 (0.06)	1.22 (0.07)	1.00 (0.27)	1.42 (0.89)	1.00 (0.21)	0.83 (0.22)
Oxides of nitrogen, NO_x	(ng/J)	166. (9.00)	144. (8.00)	144. (13.0)	134. (19.0)	112. (5.00)	110. (12.0)
Chlorides	(ng/J)	4.60 (0.76)	21.9 (15.4)	40.3 (3.85)	3.29 (0.81)	25.1 (13.7)	12.3 (4.02)
Formaldehyde	(ng/J)	3.60 (6.02)	53.2 (89.1)	0.33 (0.18)	0.08 (0.14)	0.62 (0.31)	0.18 (0.08)
Methane	(ng/J)	2.28 (1.14)	2.61 (0.68)	1.62 (0.03)	1.44 (0.40)	1.97 (0.62)	1.06 (0.25)

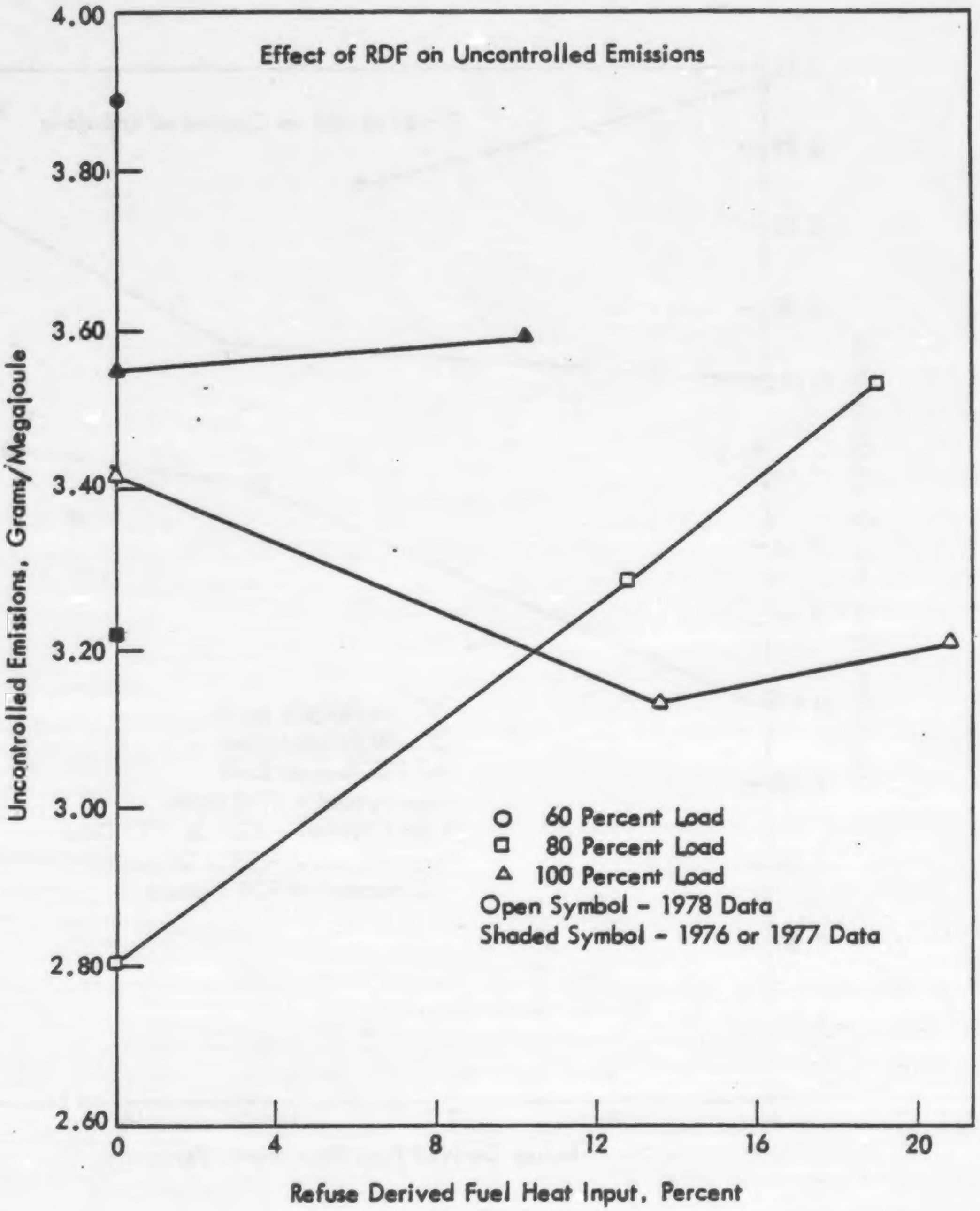

Figure 52. Uncontrolled particulate emissions.

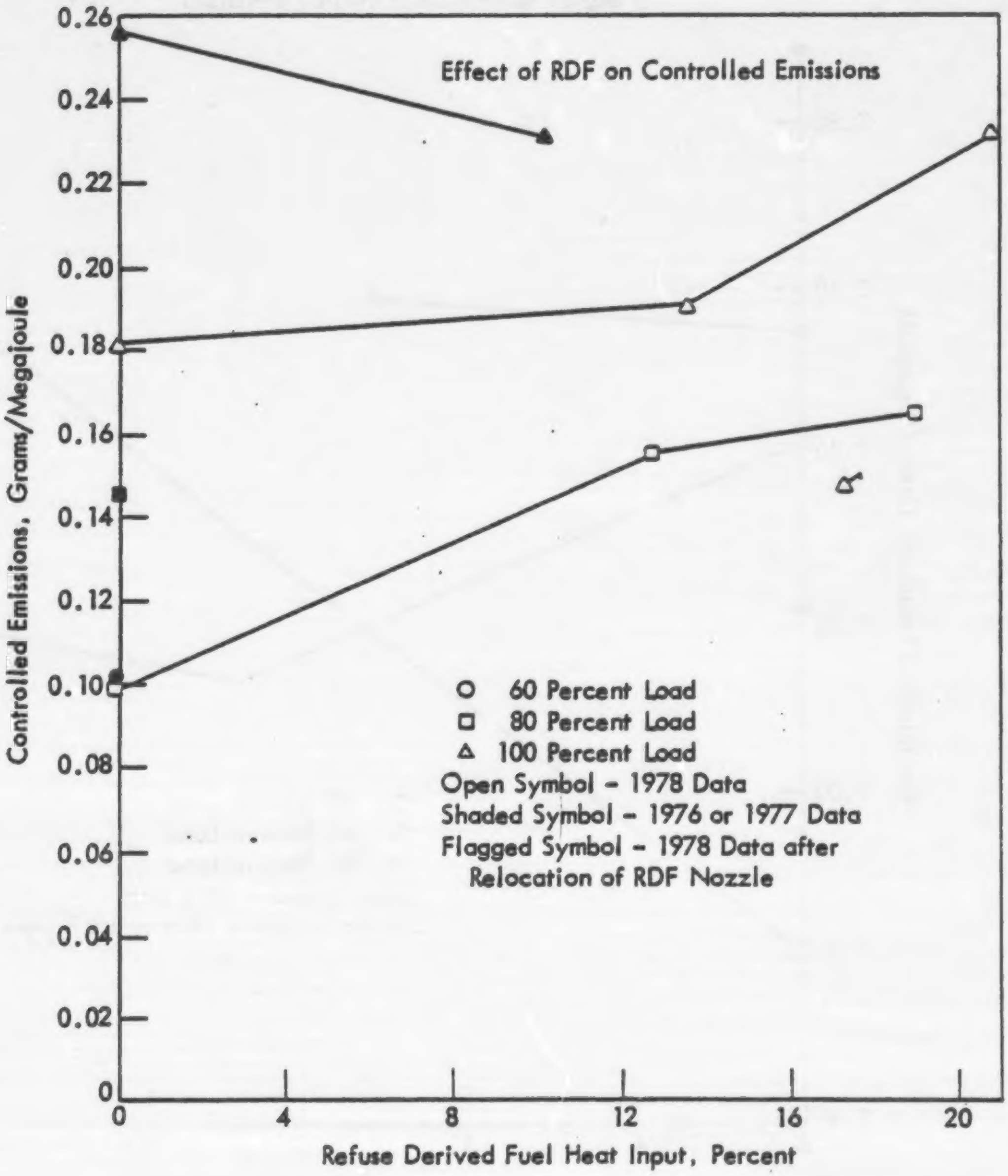

Figure 53. Controlled emissions.

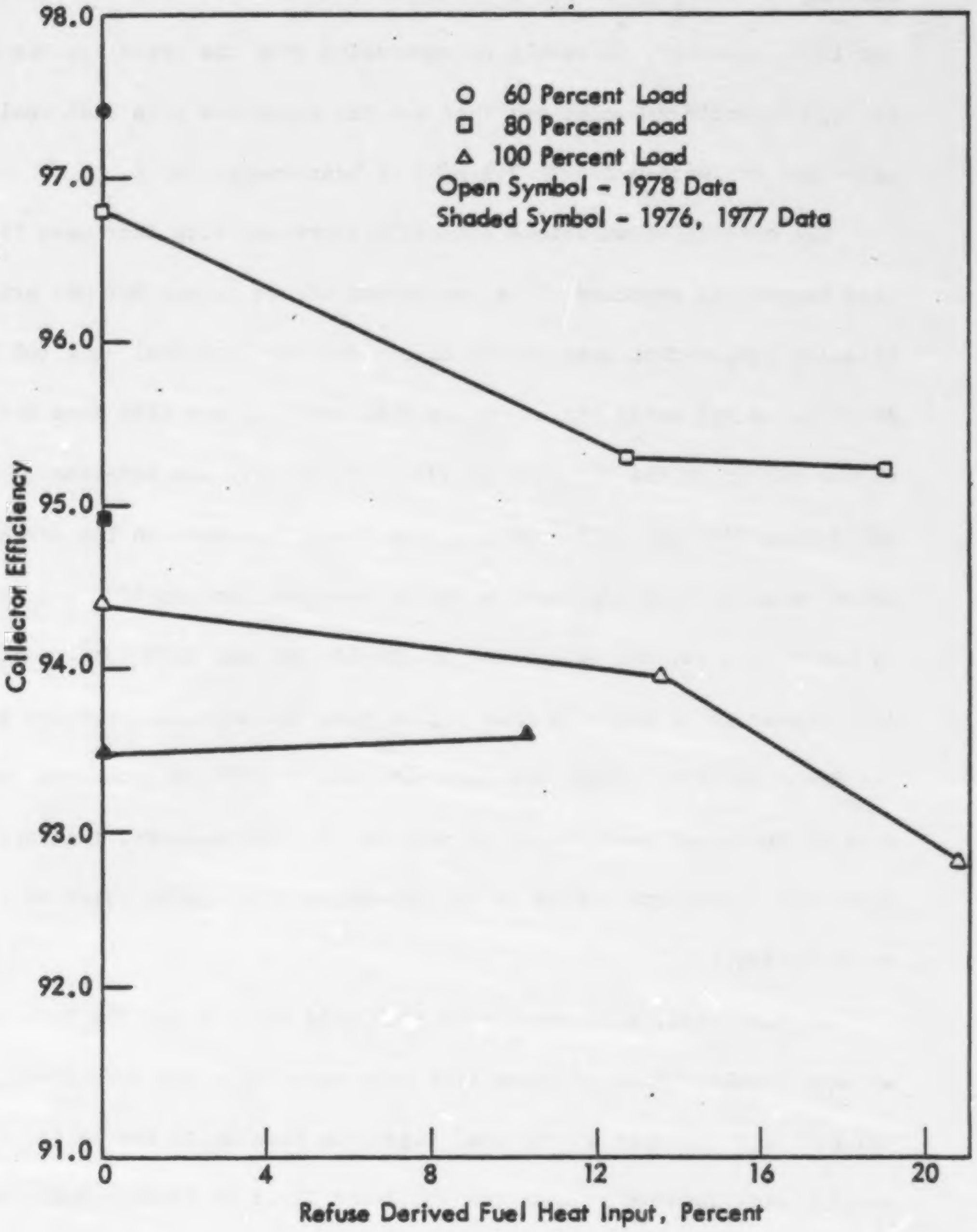

Figure 54. ESP efficiency.

This reversed trend in the 1976 data is believed to be related to difficulties in operation of the particulate collector on unit No. 7 during 1976 and 1977. However, it should be emphasized that the scale for the emissions is significantly expanded and that all the emissions with 100% coal as the only fuel are within 2.8 to 3.9 g/MJ of heat energy input.

The controlled emissions generally increased with increases in RDF. This result was expected since the amount of ash in the RDF was proportionally larger than that of the coal. For the 100% coal runs (0% RDF), the decrease in the emissions at 80 and 100% load for the 1978 data was a result of the repair of the ESP late in 1977. Difficulty was experienced with the ESP during 1976 and 1977. Some of the plate retainers in the ESP had failed, which rendered them ineffective during the test runs in 1976 and 1977. This is one reason why the emissions for the 60, 80, and 100% loads in 1976 and 1977 appear to be significantly higher than the emissions for the corresponding loads in 1978. Thus, the data obtained in 1978 is much more representative of the usual performance of unit No. 7. Furthermore, the data of 1978 show very consistent trends in the direction anticipated based on the fuel input analysis.

At 100% load, additional runs were made in 1978 for the Iowa DEQ compliance checks. Some of these runs were made after the RDF injection point was placed below that of the coal injection nozzles in the boiler. The coal nozzles were located at both the 132.5 and 129.2 ft levels, while the RDF was injected at the 127.1 ft level. For comparison, the dump grate level in the boiler was at the 100.5 ft level, so the suspension zone for the RDF was slightly less than 27 ft. The emission data presented in Figure 53 is all with the RDF injection point located between the two coal nozzles, except for the runs in which the data point plotted is flagged. The importance of the location of the RDF injection point is shown in Figure 53 and indicates that the particulate emissions can be reduced significantly by the proper location of the RDF injection point.

It should also be noted that the particulate matter collected during the runs with RDF often contained pieces of black flaky material which had passed through the ESP and into the sample trains. The black flaky substance is believed to be unburned carbon which, because of its high conductivity, passed through the ESP. While unit No. 7 was operating on RDF, some complaints were received by the Ames power plant from citizens reporting this black flaky substance having a characteristic oily residue. The substance would stick to the sides of houses and automobiles. Relocation of the RDF injection point in the boiler eliminated the problem almost completely and lowered significantly the particulate effluent from the smokestack. Lowering of the amount of particulate effluent from the smokestack because of the relocation of the RDF injection point resulted in Iowa DEQ not applying offsets to the operation of boiler unit Nos. 5 and 6 at the Ames power plant.

The effect of RDF on the ESP collector efficiency is shown in Figure 54. From this figure it is clear that the efficiency drops consistently with increases in RDF. These trends are very consistent for the data obtained in 1978 and showed the ESP efficiency to be higher at 80% load than at 100% load. The effect of the repair between 1977 and 1978 data is also apparent in this figure. For example, for the coal only runs, the collector efficiency changed from 93.4 to 94.4% efficiency at 100% load, and at the 80% load, the efficiency increased from 94.9 to 96.8%, thus demonstrating the effect the repair of the ESP had on its performance.

Figures 55 and 56 show the particulate size distribution as determined via an Andersen cascade impactor for the 80 and 100% load runs. From these figures, it is apparent that at 100% load the sizes for coal only, 10 and 20% RDF, are all about the same. At 80% load, the differences were significant. From these figures, it is apparent that particle size increases with increases in RDF.

Figures 57 and 58 show the particulate size distribution at the collector inlet and in the stack determined by a Brinks cascade impactor. Comparison of these two figures reveals the size distribution retained by the ESP. The Brinks and Andersen size distribution results for the stack particulate do not agree because the sampling probes and calibrations are different for each type of cascade impactor. Thus, comparisons can be made only in a relative sense and only for a given type of cascade impactor.

Oxides of Sulfur

The oxides of sulfur (SO_x) emitted from the boiler decreased significantly with increases in RDF as shown in Figure 59.

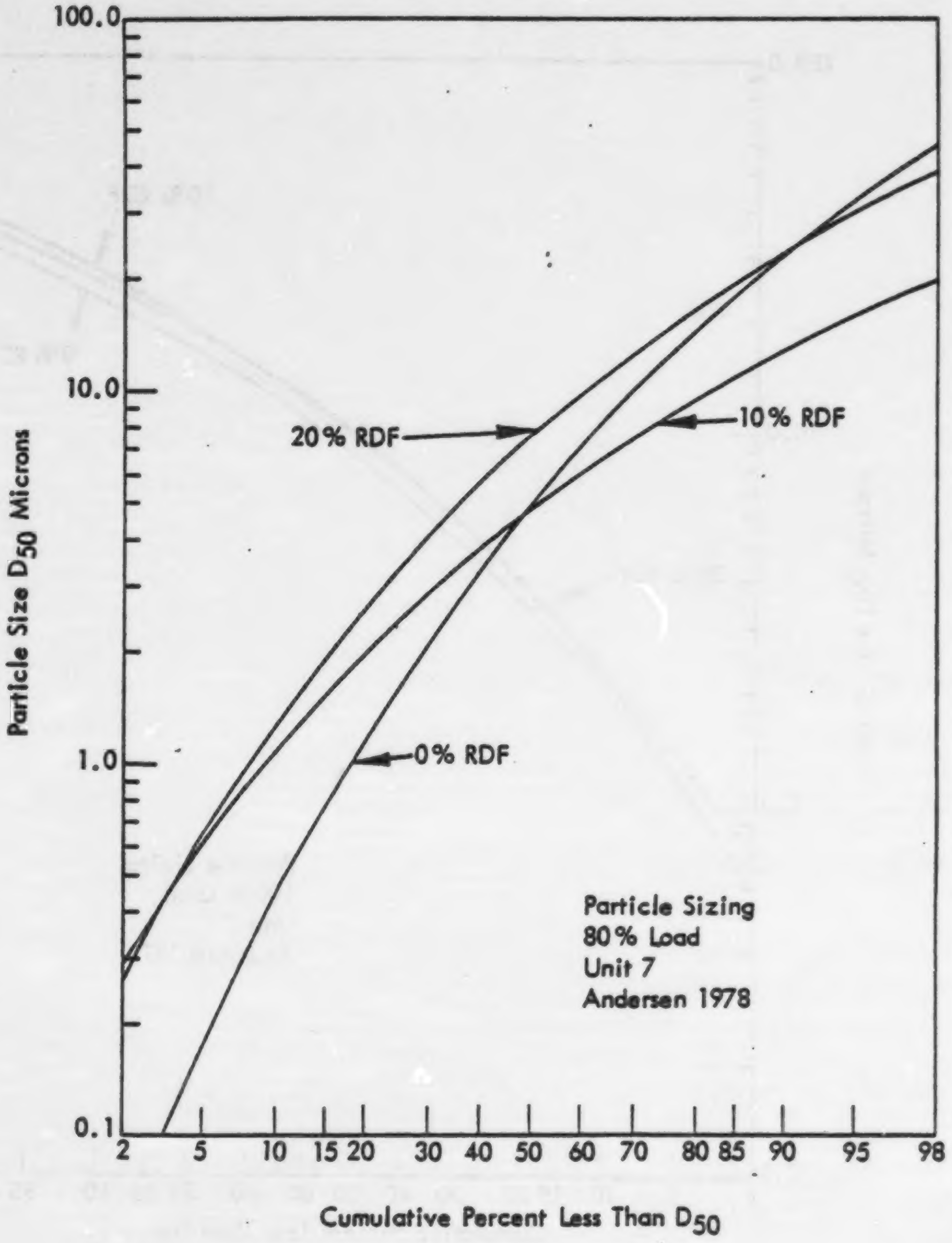

Figure 55. Andersen particle size data at 80% load.

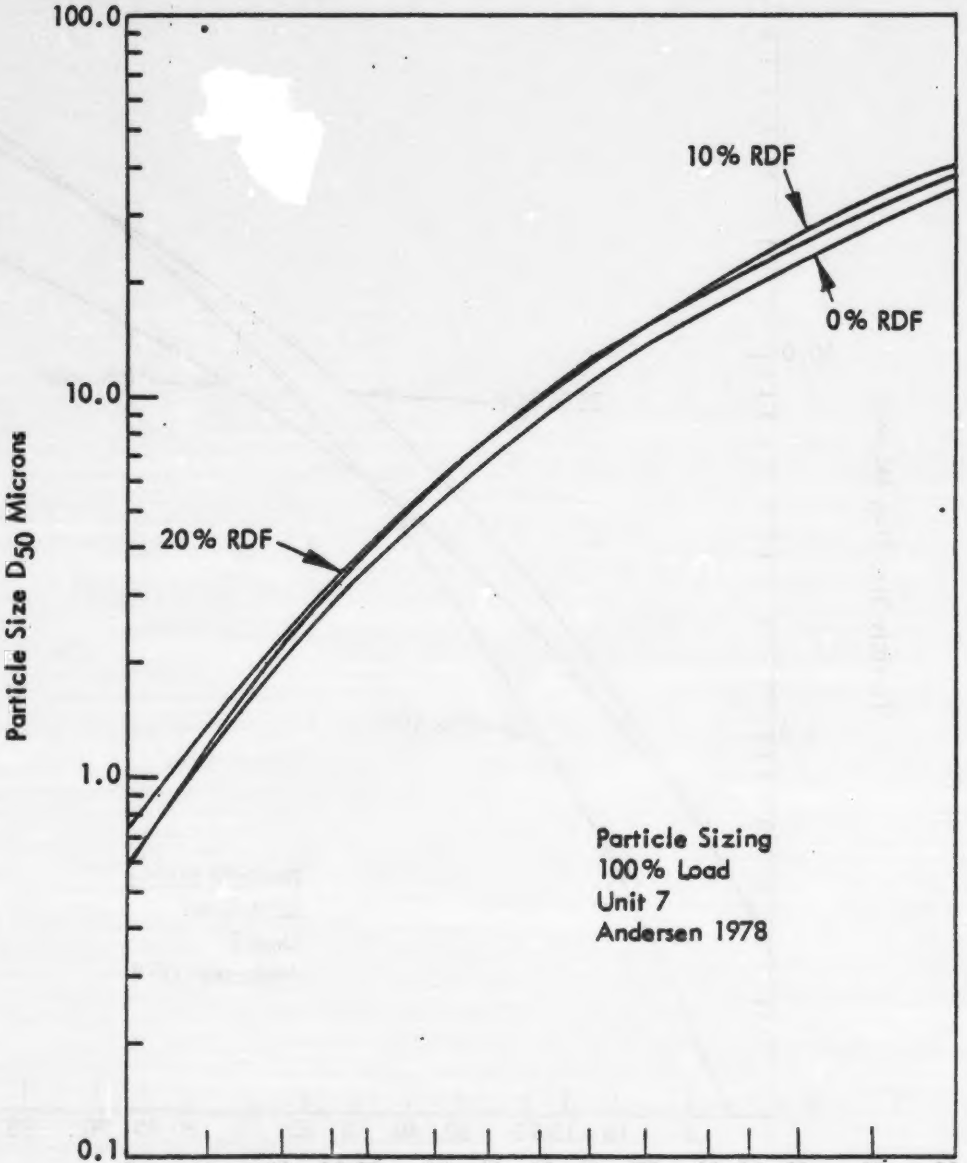

Figure 56. Andersen particle size data at 100% load.

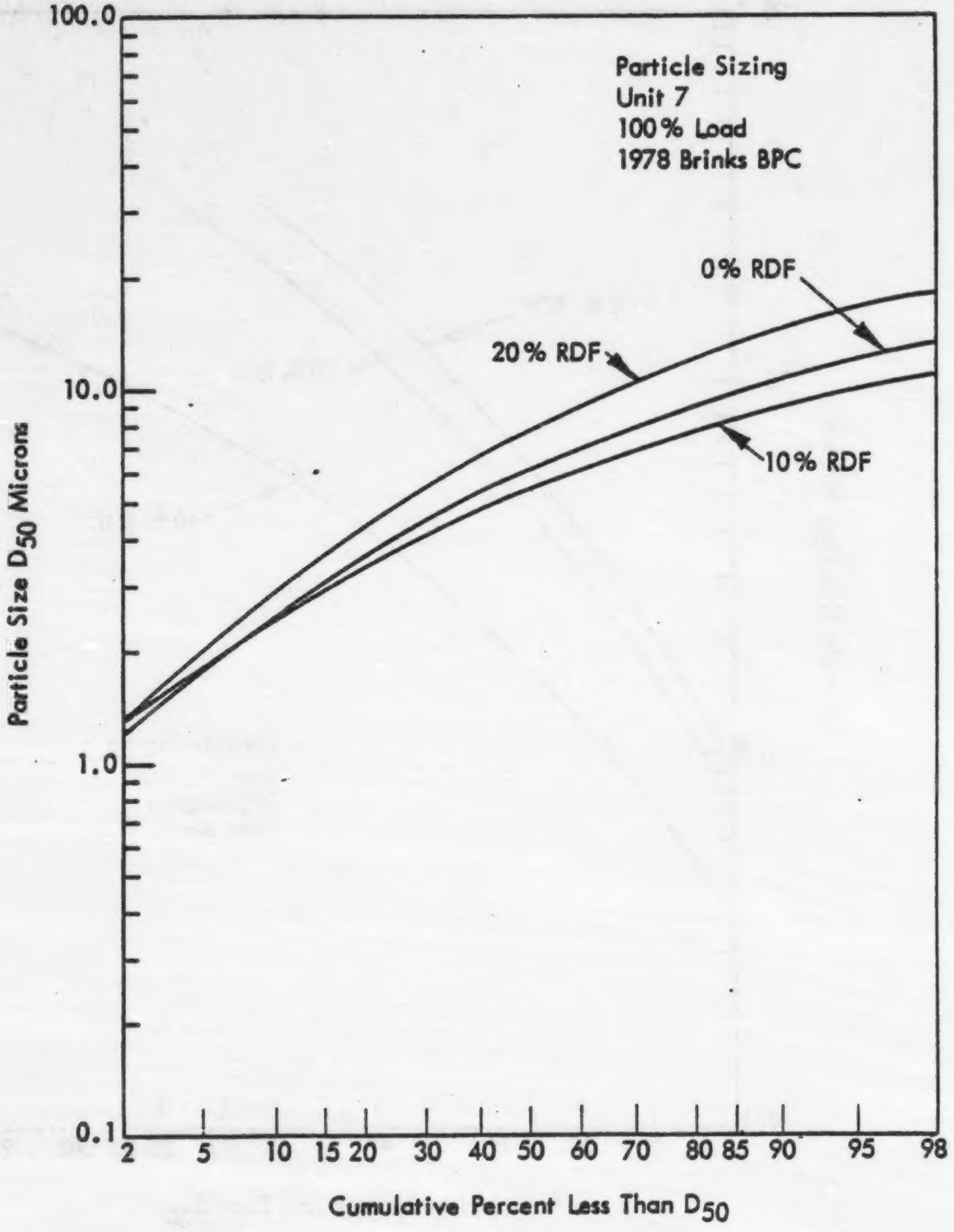

Figure 57. Brinks particle size data before the ESP.

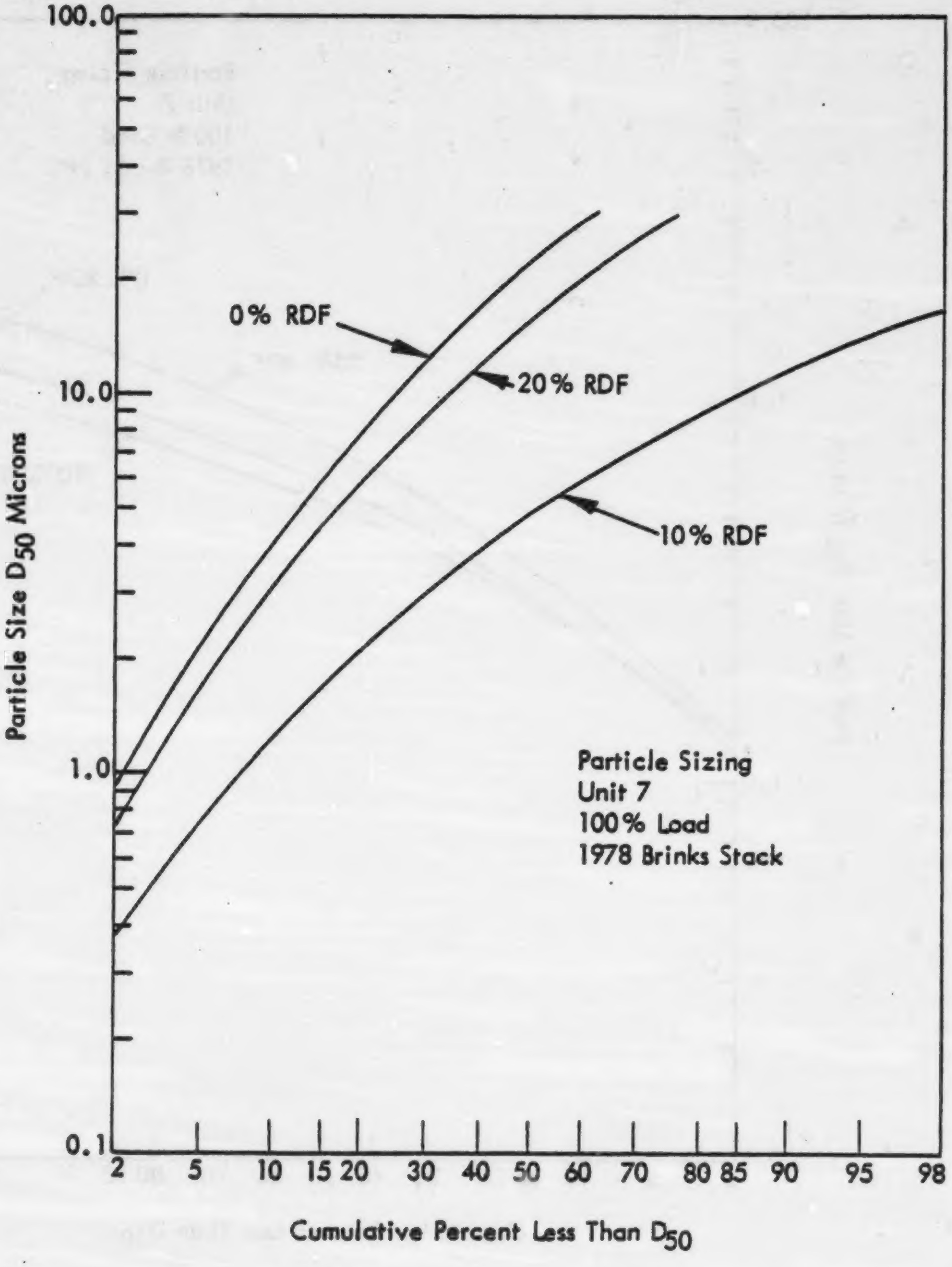

Figure 58. Brinks particle size data after the ESP.

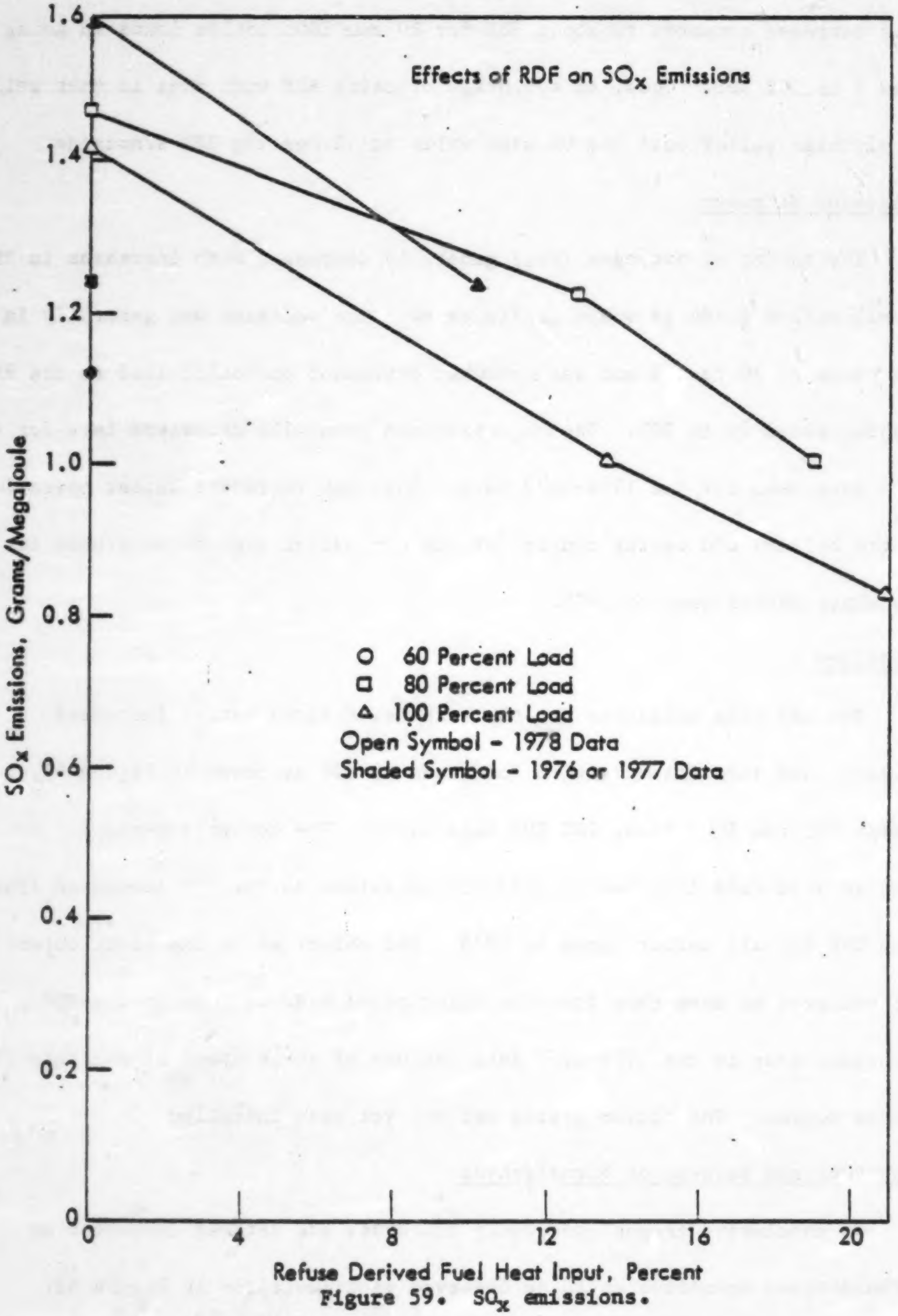

Figure 59. SO_x emissions.

This decrease amounted to about 50% for 80 and 100% boiler loads in going from 0 to 20% RDF. Thus, an advantage of using RDF with coal is that relatively high sulfur coal can be used while still meeting EPA standards.

Oxides of Nitrogen

The oxides of nitrogen (NO_x) generally decreased with increases in RDF at all boiler loads as shown in Figure 60. The decrease was generally in the range of 10 to 20% and was somewhat dependent on boiler load as the RDF was increased up to 20%. The NO_x emissions generally decreased less for the 1978 data than for the 1976-1977 data. This may represent better operation of the boilers and better control of the combustion zone temperatures for the experimental runs of 1978.

Chlorides

The chloride emissions for the suspension-fired boiler increased linearly and significantly with increases in RDF as shown in Figure 61, except for the 100% load, 20% RDF data point. The boiler experienced as much as a 10-fold increase in chloride emissions as the RDF increased from 0 to 20% for all boiler loads in 1978. The chlorides in the stack emissions are believed to have come from the chlorinated hydrocarbons in the RDF. The chlorides drop in the 1976-1977 data because of the dropout of RDF into the bottom hopper. The bottom grates had not yet been installed.

Aldehydes and Ketones of Formaldehyde

No conclusive trends concerning aldehydes and ketones (reported as formaldehyde) emissions could be observed as illustrated in Figure 62.

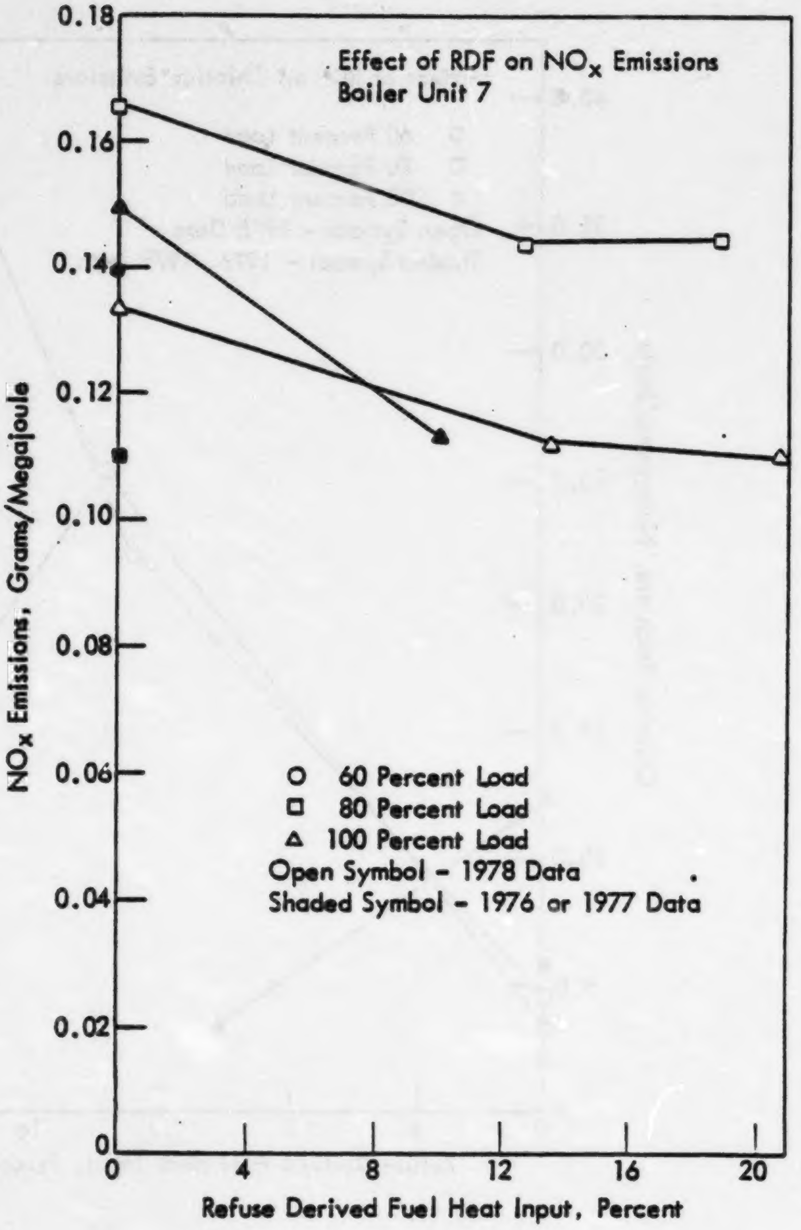

Figure 60. NO_x emissions.

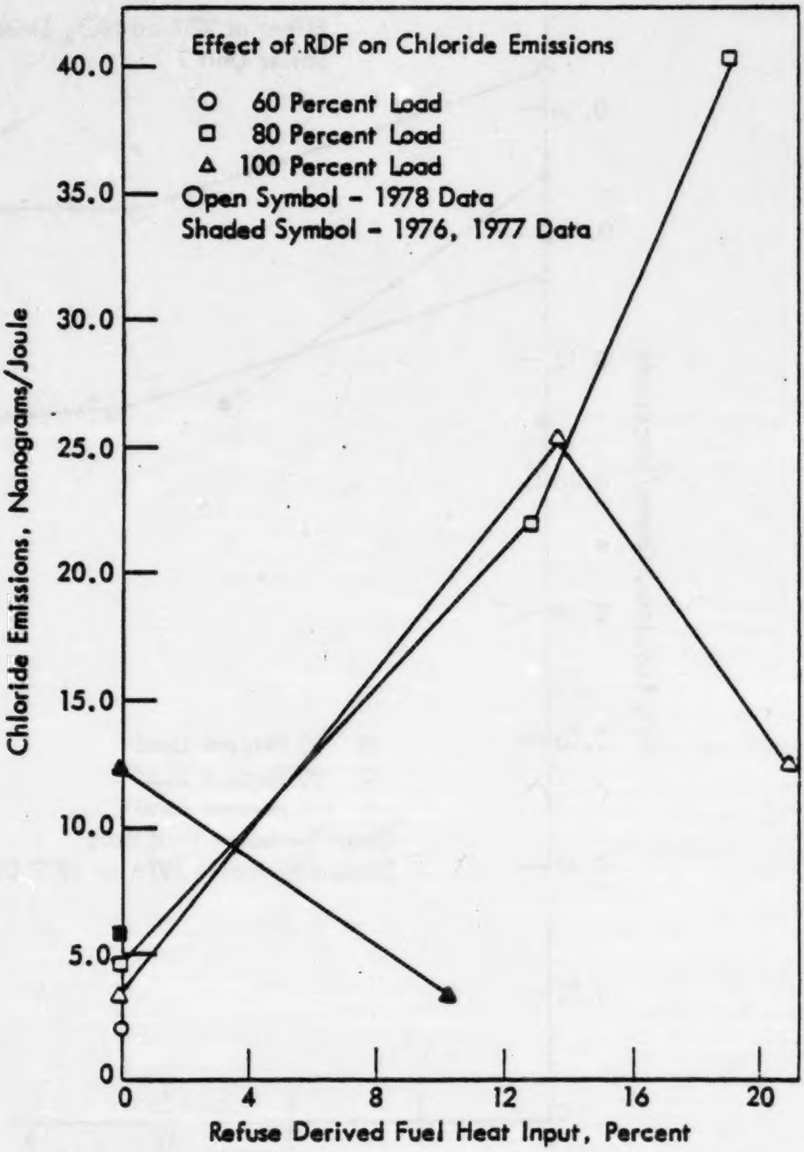

Figure 61. Chloride emissions.

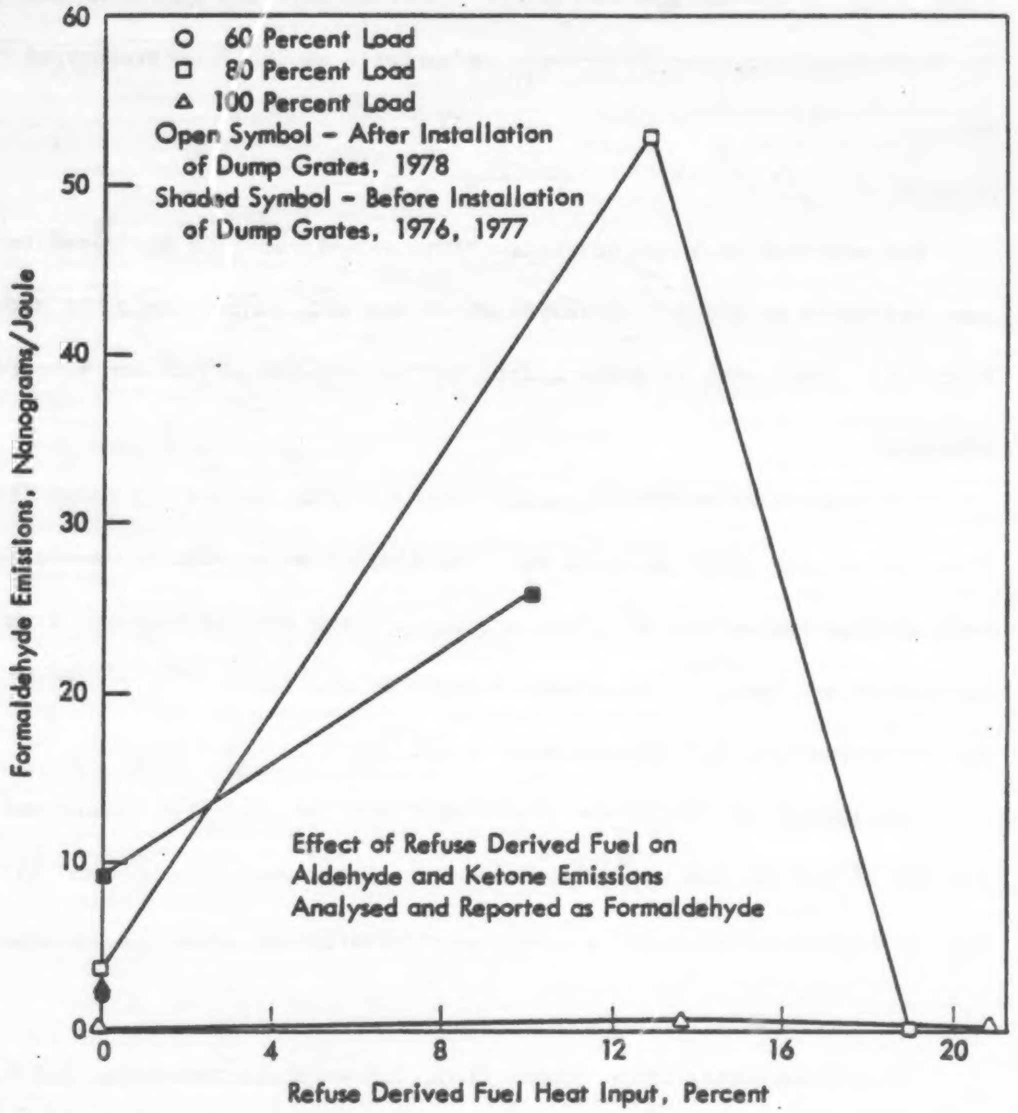

Figure 62. Formaldehyde emissions.

Formaldehyde emissions depend on the constituents of the RDF such as wood chips, leaves, and other cellulose fiber. No control of the quantity of these items in the RDF was attempted. Consequently, the emissions due to the burning of cellulose fiber were as variable as the constituency of the RDF.

Methane

The unburned (C_1) hydrocarbons (methane) emitted from the stack increased, then decreased as the RDF increased to 10 and 20%, respectively, as shown in Figure 63. The level of methane detected is very low, which was expected.

Organics

The amounts of polychlorinated biphenyls (PCB) in the fly ash collected from the ESP are given in Table 60. The field samples were processed by both Soxhlet extraction and sonic extraction; the amounts measured from each extraction are reported in columns 4 and 5 of the table. The superiority of Soxhlet extraction for PCB analyses is evident.

The amounts of PCB in the stack vapor samples collected before and after the ESP of the fly ash were also measured. These data are reported in Table 61. Important conclusion: A significant fraction of stack PCB is removed by ESP.

Other chlorinated hydrocarbons (HC), 1,2,4-trichlorobenzene, 1,2,4,5-tetrachlorobenzene, hexachlorobenzene, and 1-chloronaphthalene were also identified by GC/MS in the extracts from the fly ash samples. The amounts of these components were measured by electron capture gas chromatography (ECGC). The values are reported in Table 62.

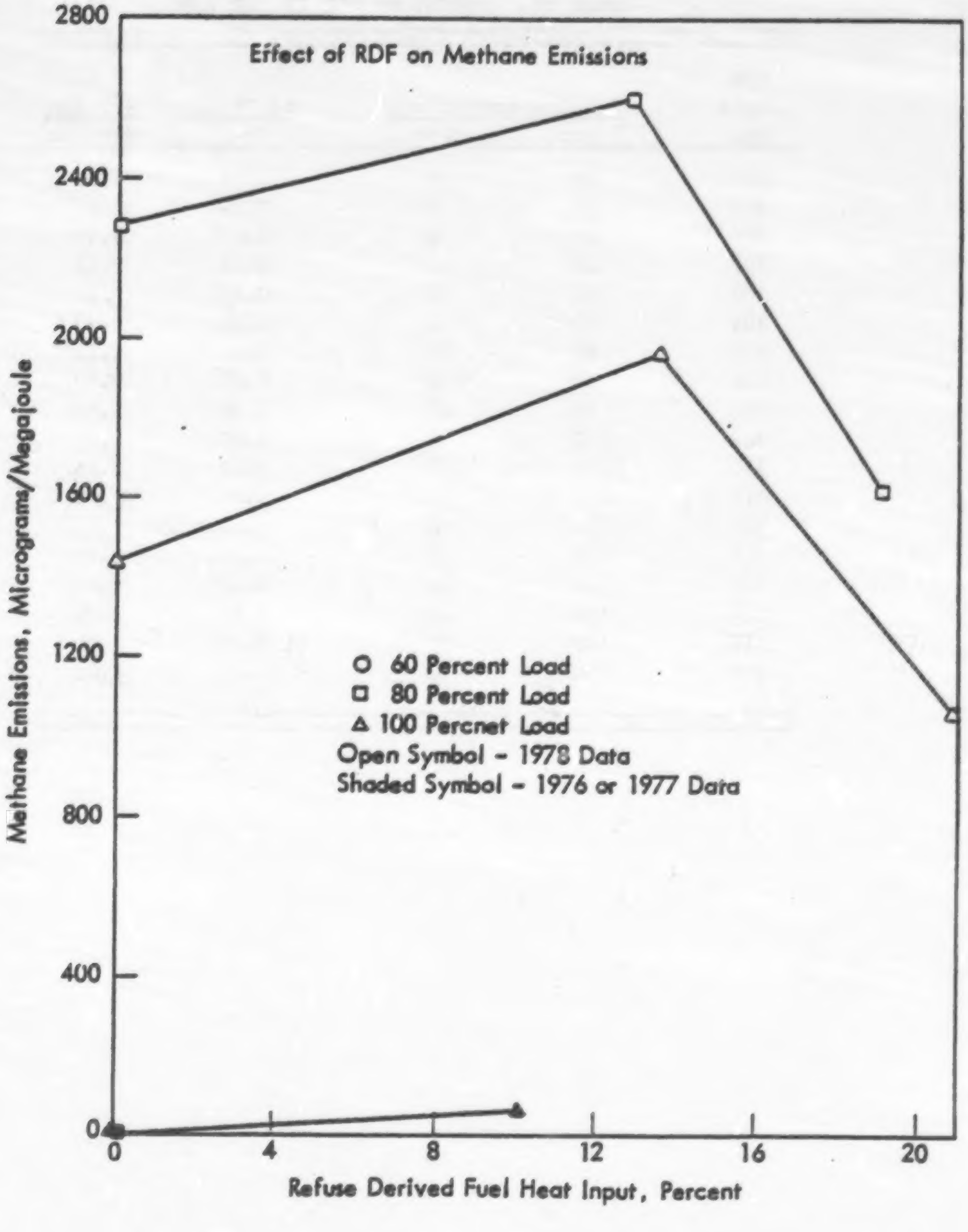

Figure 63. Methane emissions.

TABLE 60. AMOUNT OF PCB IN FLY ASH

EPA sample No.	Burning conditions		ng PCB/g	Fly ash
	% Load	% Refuse	Sonic	Soxhlet
304	80	0	0.33	1.00
305	80	0	0.69	1.00
306	80	0	0.49	0.99
307	80	10	0.45	2.13
308	80	10	0.67	1.27
309	80	10	0.45	1.73
301	80	20	0.56	1.53
302	80	20	0.54	1.40
303	80	20	1.08	1.53
312	100	0	0.30	1.06
314	100	0	0.15	3.15
315	100	0	0.44	0.99
310	100	10	1.12	2.27
311	100	10	0.54	1.73
318	100	10	0.47	1.41
313	100	20	1.00	2.00
316	100	20	0.70	0.76
317	100	20	0.46	1.21

TABLE 61. AMOUNT OF PCB IN THE STACK VAPOR PHASE

EPA sample No.	PCB in ng/liter	
	Before ESP	After ESP
305V	not measured	0.07
306V	not measured	0.06
307V	0.11	0.03
308V	0.16	0.07
309V	not measured	0.22
310V	0.02	0.10
311V	0.09	0.06
312V	0.10	0.06
313V	0.25	not measured
314V	0.22	0.11
315V	0.14	0.03
316V	0.21	0.05
317V	0.19	0.03
318V	0.08	0.04

TABLE 62. AMOUNT OF CHLORINATED HYDROCARBONS IN FLY ASH

EPA sample No.	ng Chlorinated HC/g fly ash			
	1,2,4-Trichlorobenzene	1,2,4,5-Tetrachlorobenzene	1-Chloronaphthalene	Hexachlorobenzene
301	0.35	0.02	0.48	0.04
302	0.79	0.08	1.68	0.10
303	0.35	0.03	0.48	0.04
304	0.27	-	-	0.03
305	0.38	-	-	0.10
306	-	-	-	-
307	0.53	-	-	0.02
308	0.89	-	0.64	0.13
309	0.39	-	-	0.05
310	1.71	0.09	1.20	0.17
311	1.37	0.07	1.04	0.07
312	0.63	-	0.32	0.03
313	1.05	-	0.56	0.03
314	0.17	0.08	-	0.04
315	0.13	-	-	0.03
316	0.83	-	-	0.02
317	0.04	-	-	-
318	1.11	0.06	-	0.09

Trace Elements

A series of 19 trace elements were sampled from all input and output streams associated with the operation of steam generator unit No. 7. Table 63 lists the trace elements detected in the input fuels of coal and RDF used during the test. The elements selected for analysis are listed by rank order; the ranking was determined by the concentration given in parts per million (ppm). The standard deviations are also listed. Another column in Table 63 also shows the amount of the trace element listed on the basis of mass per unit of energy input to the boiler. The values listed in Table 63 are overall averages for both coal and RDF. The trace elements with higher proportions of concentration in coal than in RDF are identified in this table as strontium, beryllium, nickel, and germanium. The elements that were not detected based on the detection limit of the analytical instrumentation are also indicated. Elements relatively high in concentration in the RDF are zinc, lead, copper, manganese, and vanadium.

Table 64 lists the trace elements detected in the bottom ash, hopper ash (fly ash), and particulate matter collected in the smokestack of unit No. 7. These elements are listed in rank order based on mass of the element per unit of energy input to the boiler. The detection limits of the XRF device used to analyze for trace elements in the solid materials collected in the output stream samples is also indicated. These amounts are in units of parts per million by weight of the element, except for the stack filters which are given in micrograms per square centimeter of area over which the

TABLE 63. TRACE ELEMENT CONTENT OF COAL AND RDF USED AS FUEL IN BOILER UNIT NO. 7

Coal			RDF		
	Level[a]			Level[a]	
Element	ppm	ng/J	Element	ppm	ng/J
Strontium[b]	86 ± 28	2.92 ± 1.15	Zinc	763 ± 345	4.65 ± 2.13
Vanadium	83 ± 16	2.92 ± 1.15	Lead	613 ± 289	3.89 ± 2.27
Manganese	76 ± 23	2.92 ± 0.52	Copper	572 ± 854	3.58 ± 5.74
Zinc	66 ± 41	2.39 ± 1.46	Manganese	194 ± 47	1.18 ± 0.33
Beryllium[b]	37 ± 12	1.55 ± 0.49	Vanadium	154 ± 32	0.94 ± 0.19
Lead	36 ± 13	1.26 ± 0.48	Strontium	46 ± 11	0.28 ± 0.04
Tin	20 ± 5	0.71 ± 0.17	Chromium	34 ± 8	0.28 ± 0.04
Chromium	19 ± 7	0.74 ± 0.35	Tin	27 ± 8	0.17 ± 0.06
Nickel[b]	18 ± 5	0.63 ± 0.17	Antimony	25 ± 17	0.15 ± 0.11
Copper	15 ± 3	0.52 ± 0.08	Gallium	16 ± 3	0.10 ± 0.02
Germanium[b]	5.3 ± 0.9	0.19 ± 0.04	Nickel	14 ± 4	0.09 ± 0.03
Gallium	2.5 ± 0.5	0.09 ± 0.02	Selenium	8 ± 1	0.05 ± 0.01
Antimony	BDL	BDL	Cadmium	6.4 ± 8.1	0.04 ± 0.05
Selenium	BDL	BDL	Germanium	1.7 ± 0.3	0.01 ± 0.00
Thallium	BDL	BDL	Thallium	BDL	BDL
Mercury	BDL	BDL	Mercury	BDL	BDL
Arsenic	BDL	BDL	Arsenic	BDL	BDL
Cadmium	BDL	BDL	Beryllium	BDL	BDL
Cobalt	BDL	BDL	Cobalt	BDL	BDL

Note: BDL signifies the element is below the analytical instrumentation detection limit.

[a] Values listed are overall averages for the coal and RDF used during 1978 tests.

[b] Trace elements with higher proportions in coal than in RDF.

TABLE 64. TRACE ELEMENT CONTENT OF BOTTOM ASH, HOPPER FLY ASH, AND STACK FLY ASH

	Bottom ash					Hopper ash				Particulate on stack filters				
	Detection	Level				Level					Detection	Level		
Element	limits (ppm)a/	Max (ppm)	Max (ng/J)	Avg ± std dev (ng/J)	Element	Max (ppm)	Max (ng/J)	Avg ± std dev (ng/J)		Element	limits (mg/cm²)	Max (mg/cm²)	Max (pg/J)	Avg ± std dev (pg/J)
Chromium	(100)	2,450	56.2	0.913 ± 1.40	Zinc	2,250	107.4	4.717 ± 2.428		Zinc	(0.2)	82	125.0	35.35 ± 26.26
Manganese	(70)	1,200	26.6	0.950 ± .805	Manganese	1,320	58.0	3.469 ± 1.178		Lead	(1)	30	37.4	18.94 ± 13.19
Zinc	(20)	1,680	26.2	0.964 ± 0.790	Lead	1,640	57.6	2.994 ± 1.849		Vanadium	(1)	8	11.0	7.00 ± 1.46
Lead	(25)	1,240	16.8	0.634 ± 0.534	Vanadium	1,030	36.7	2.744 ± 0.623		Strontium	(0.1)	10	13.7	6.66 ± 2.40
Nickel	(20)	680	15.6	0.261 ± 0.387	Strontium	1,130	33.3	2.296 ± 0.600		Manganese	(0.5)	10	10.4	5.46 ± 2.11
Copper	(20)	910	14.0	0.433 ± 0.442	Chromium	404	14.4	0.861 ± 0.259		Germanium	(0.4)	1.7	2.59	1.39 ± 0.54
Vanadium	(200)	660	13.3	0.448 ± 0.361	Copper	218	7.59	0.417 ± 0.189		Copper	(0.2)	2.6	2.69	13.5 ± 0.58
Strontium	(5)	750	10.3	0.359 ± 0.274	Nickel	140	4.70	0.306 ± 0.084		Chromium	(0.5)	1.6	2.43	1.33 ± 0.55
Gallium	(10)	320	5.8	0.055 ± 0.133	Gallium	86	3.30	0.172 ± 0.083		Gallium	(0.4)	1.5	2.28	1.31 ± 0.67
Tin	-	160	1.1	0.034 ± 0.034	Germanium	51	2.48	0.126 ± 0.039		Nickel	(0.3)	1.2	1.65	1.24 ± 0.48
Beryllium	(10)	120	0.013	0.011 ± 0.002	Tin	59	2.00	0.096 ± 0.068		Selenium	(0.2)	<0.5	0.79	0.43 ± 0.15
Antimony	-	230	0.436	0.096 ± 0.117	Beryllium	120	0.31	0.249 ± 0.057		Arsenic	(0.2)	BDL	BDL	BDL
Selenium	(5)	BDL	BDL	BDL	Cadmium	11	0.05	0.019 ± 0.015		Beryllium	-	N.A.	N.A.	N.A.
Thallium	-	BDL	BDL	BDL	Antimony	92	0.30	0.139 ± 0.116		Cadmium	-	BDL	BDL	BDL
Germanium	(10)	BDL	BDL	BDL	Selenium	BDL	BDL	BDL		Cobalt	(0.4)	BDL	BDL	BDL
Mercury	-	BDL	BDL	BDL	Thallium	BDL	BDL	BDL		Mercury	-	BDL	BDL	BDL
Arsenic	(10)	BDL	BDL	BDL	Mercury	BDL	BDL	BDL		Antimony	-	BDL	BDL	BDL
Cadmium	-	BDL	BDL	BDL	Arsenic	BDL	BDL	BDL		Tin	-	BDL	BDL	BDL
Cobalt	(30)	BDL	BDL	BDL	Cobalt	BDL	BDL	BDL		Thallium	-	BDL	BDL	BDL

a/ Detection limits for bottom ash and hopper ash are the same.

particulate is collected on the filter. Trace elements of relatively high concentration in the fly ash are zinc, lead, manganese, vanadium, and strontium. Along with nickel, copper, and chromium, these elements are high in relative concentration in the bottom ash. Table 65 lists the trace elements detected in the exhaust gas stream from the smokestack of unit No. 7. The trace elements were condensed or collected in solution in two sample trains. Water was used in the particulate sample train in which the flow rate through the train was relatively high, about 10 liters/min. The flow rate through the trace element sample train was relatively low, about 1 liter/min. (The flow rates were indicated in Table 3.) The solutions in the trace elements train were sodium hydroxide (in an impinger used as a prescrubber) followed by two impingers which contained iodine monochloride. The analysis of the trace elements used in this sample train have been combined to include the total amount collected in the sodium hydroxide prescrubber and both of the iodine monochloride impingers. All of the trace elements found in the solution of the sample trains have been analyzed by the ICP technique. The only elements detected in the impinger solutions of both sample trains were cobalt and arsenic. However, other elements consistently detected were mercury, selenium, zinc, copper, manganese, and tin.

Table 66 lists the trace elements detected in the sluice water. Sluiced material from the bottom pit of unit No. 7 passes through a pipeline approximately 400 m into an ash pond where the sluice water samples and bottom ash samples were collected by the Fiscus-Joensen technique. Here,

TABLE 65. TRACE ELEMENTS CONDENSED OR ABSORBED IN IMPINGER SOLUTIONS OF SAMPLE TRAIN

	Trace element sample train (impinger ICL)					Particulate sample train (impinger H_2O)			
	Detection[a]	Level				Detection[a]	Level		
Element	limit (mg/ℓ)	ICL max (mg/ℓ)	Max (pg/J)	Avg ± std dev (pg/J)	Element	limit (mg/ℓ)	Max (mg/ℓ)	Max (pg/J)	Avg ± std dev (pg/J)
Cobalt	0.05	0.284	1741	234 ± 403	Cobalt	0.002	0.193	14.9	3.18 ± 4.06
Arsenic	0.40	<0.400	943	385 ± 208	Mercury	0.10	0.299	14.7	4.46 ± 3.04
Zinc	0.02	0.617	233	70.6 ± 53.4	Arsenic	0.05	0.082	8.00	5.26 ± 1.21
Copper	0.01	0.095	55.0	25.6 ± 21.9	Selenium	0.04	0.060	5.78	3.81 ± 0.98
Manganese	0.004	0.136	45.3	9.5 ± 10.6	Tin	0.04	0.270	5.60	4.07 ± 0.87
Beryllium	0.001	BDL**	BDL	BDL	Beryllium	0.00005	BDL	BDL	BDL
Cadmium	0.10	BDL	BDL	BDL	Cadmium	0.003	BDL	BDL	BDL
Chromium	0.08	BDL	BDL	BDL	Chromium	0.0005	BDL	BDL	BDL
Gallium	0.23	BDL	BDL	BDL	Copper	0.01	BDL	BDL	BDL
Germanium	0.30	BDL	BDL	BDL	Gallium	0.01	BDL	BDL	BDL
Mercury	0.22	BDL	BDL	BDL	Germanium	0.01	BDL	BDL	BDL
Nickel	0.17	BDL	BDL	BDL	Manganese	0.001	BDL	BDL	BDL
Lead	1.80	BDL	BDL	BDL	Nickel	0.07	BDL	BDL	BDL
Antimony	0.42	BDL	BDL	BDL	Lead	0.05	BDL	BDL	BDL
Selenium	0.63	BDL	BDL	BDL	Tin	0.025	BDL	BDL	BDL
Tin	0.23	BDL	BDL	BDL	Strontium	0.02	BDL	BDL	BDL
Strontium	0.28	BDL	BDL	BDL	Thallium	0.1	BDL	BDL	BDL
Thallium	7.5	BDL	BDL	BDL	Vanadium	0.004	BDL	BDL	BDL
Vanadium	0.06	BDL	BDL	BDL	Zinc	0.02	BDL	BDL	BDL

** Note: BDL indicates below the analytical instrument detection limit.

[a] Detection limit of the primary chemical, ICL is given.

TABLE 66. TRACE ELEMENTS DETECTED IN BOILER BOTTOM ASH SLUICE WATER

Element	Detection limit (mg/ℓ)	Blank level (mg/ℓ)	Max value (mg/ℓ)	Avg ± std dev value (mg/ℓ)
Strontium	0.07	0.271	0.372	0.267 ± 0.047
Antimony	0.025	BDL	0.233	0.069 ± 0.061
Arsenic	0.05	0.083	0.100	0.074 ± 0.018
Mercury	0.035	0.042	0.05	0.041 ± 0.017
Manganese	0.001	0.212	0.04	0.008 ± 0.013
Copper	0.0005	BDL	0.04	0.004 ± 0.010
Chromium	0.003	BDL	0.02	0.006 ± 0.005
Vanadium	0.004	BDL	0.01	0.006 ± 0.002
Cobalt	0.002	0.010	0.01	0.003 ± 0.002
Beryllium	0.0005	BDL	BDL	BDL
Cadmium	0.003	BDL	BDL	BDL
Gallium	0.01	BDL	BDL	BDL
Nickel	0.07	BDL	BDL	BDL
Lead	0.05	BDL	BDL	BDL
Selenium	0.04	BDL	BDL	BDL
Tin	0.04	BDL	BDL	BDL
Zinc	0.02	BDL	BDL	BDL
Thallium	0.10	BDL	BDL	BDL
Germanium	0.01	BDL	BDL	BDL

the levels of strontium, antimony, arsenic, and mercury were at their highest relative levels, and all were at values less than 0.4 mg/liter.

Table 67 lists the trends of the trace elements that are in the output streams and whether they either increase, decrease, or remain constant with respect to the amount of RDF coming in with the input fuel. The plus signs indicate an increase of the trace element with increased amounts of RDF used in the input fuel, whereas the negative sign indicates a decrease in the amount of trace elements with respect to increases in RDF in the input fuel. A zero indicates no detectable trend within the data scatter. Those elements detected in the stack effluent consistently increasing with increases in RDF were manganese, zinc, lead, copper, gallium, and chromium.

Table 68 lists the estimated trace elements in the ambient air in terms of a stack gas concentration in terms of milligrams per cubic meter of stack gas. An estimate of the concentration of the element in the ambient air is obtained by dividing the flue gas concentration by a factor of 1,000 to yield the ambient air estimate of the element concentration. The estimate of the ambient air concentration is then compared to the threshold limit value (TLV) of the element. The ratio of the estimated ambient air concentration to the TLV has been listed in this table to approximate the relative toxicity of the elements scanned during the tests. Finally, a comparison has been made between the data from this study and the predictions listed in Reference 9 from the St. Louis data. From the St. Louis study, it was predicted that chromium (10.2), copper (7.4), lead (3.7), and

TABLE 67. TRENDS OF TRACE ELEMENT VARIATION WITH RDF INPUT TO BOILER UNIT NO. 7

Element	Bottom ash	Hopper ash	Stack particulate filter	Stack impinger water	Stack impinger ICl-NaOH	Sluice water
Antimony	+[a]	+	BDL[b]	BDL	BDL	0[c]
Arsenic	BDL	BDL	BDL	0	0	0
Beryllium	-[d]	-	N.A.[e]	BDL	BDL	BDL
Cadmium	BDL	+	BDL	BDL	BDL	BDL
Chromium	+	+	+	BDL	BDL	BDL
Cobalt	BDL	BDL	BDL	0	-	BDL
Copper	+	+	+	BDL	0	0
Gallium	+	+	+	BDL	BDL	BDL
Germanium	BDL	0	0	BDL	BDL	BDL
Lead	+	+	+	BDL	BDL	BDL
Nickel	+	0	0	BDL	BDL	BDL
Manganese	+	+	+	+	BDL	BDL
Mercury	BDL	BDL	BDL	+	BDL	BDL
Selenium	BDL	BDL	0	0	BDL	BDL
Strontium	+	+	0	BDL	BDL	0
Tin	+	+	BDL	0	BDL	BDL
Thallium	BDL	BDL	BDL	BDL	BDL	BDL
Vanadium	+	+	0	BDL	BDL	0
Zinc	+	+	+	BDL	0	BDL

[a] + indicates an increasing trend with RDF increases.

[b] BDL indicates levels were below the detection limit of the analytical instrument.

[c] 0 indicates a lack of any definite trend.

[d] - indicates a decreasing trend with RDF increases.

[e] N.A. indicates that no analysis was available.

TABLE 68. TRACE ELEMENT CONCENTRATION FROM STACK FLUE GAS AS AN ESTIMATE FOR AMBIENT AIR CONCENTRATION

Element	TLV (mg/m^3)	Concentration from filter (mg/m^3)	Concentration from trace element train (mg/m^3)	Filter conc.[a] / TLV	Trace element train[a] / TLV	St. Louis[a] flue gas concentration (mg/m^3)	St. Louis conc. / TLV
Antimony	0.5	BDL[b]	BDL	-	-	0.022	0.044
Arsenic	0.5	BDL	0.873	-	1.746	0.005	0.010
Beryllium	0.002	BDL	BDL	-	-	0.000	0.000
Cadmium	0.20	BDL	BDL	-	-	0.007	0.035
Chromium	0.05	0.003	BDL	0.060	-	0.511	10.220
Cobalt	0.1	BDL	0.530	-	5.300	0.085	0.850
Copper	0.1	0.003	0.058	0.030	0.580	0.735	7.350
Gallium	-	0.003	BDL	-	-	0.003	-
Germanium	-	0.003	BDL	-	-	0.001	-
Lead	0.15	0.043	BDL	0.287	-	0.556	3.707
Manganese	5	0.012	0.103	0.002	0.021	0.198	0.040
Mercury	0.05	BDL	BDL	-	-	-	-
Nickel	1	0.003	BDL	0.003	-	0.212	0.212
Selenium	0.2	0.001	BDL	0.005	-	0.001	0.005
Strontium	-	0.015	BDL	-	-	0.151	-
Tin	2	BDL	BDL	-	-	0.033	0.017
Thallium	0.1	BDL	BDL	-	-	0.000	0.000
Vanadium	0.5	0.016	BDL	0.032	-	0.009	0.018
Zinc[c]	1	0.080	0.160	0.080	0.160	1.240	1.240

[a] Stack concentrations are divided by 1,000.

[b] BDL indicates levels below the detection limit of the analytical instrument.

[c] Values are for $ZnCL_2$.

zinc (1.2) would be above the TLV and of relative significance in the order given. None of the trace elements detected on the stack particulate train filters during these studies have predicted ambient air concentration above the TLV, although the lead level is near 30% of the TLV. However, from the trace element sampling train, cobalt (5.3) and arsenic (1.7) are indicated to be above the TLV for the Ames study.

Table 69 lists the minor constituents found in the coal, RDF, bottom ash, and fly ash for the 1978 test runs on unit No. 7. The elements listed are aluminum, silicone, sulfur, potassium, calcium, iron, and titanium.

Figures 64 and 65 are plots of fuel enrichment factors of the trace elements to show the relative importance of RDF in causing increased emissions of the trace elements scanned in this study. From these figures, it can be seen that the elements of zinc, copper, lead, and gallium are significantly increased with RDF over coal alone. Zinc comes into the RDF from paper where it is used as a filler material; lead and copper from inks used in newsprint and colored pictures; and the gallium is felt to be an impurity that comes into the RDF along with another element such as aluminum.

TABLE 69. PERCENTAGE OF MINOR CONSTITUENTS IN COAL, RDF, BOTTOM ASH, AND HOPPER FLY ASH

Fuels - Summary of all 1978 runs

Coal		RDF	
Element	Avg ± std dev	Element	Avg ± std dev
Al	1.29 ± 0.17	Al	1.36 ± 0.48
Si	1.94 ± 0.25	Si	2.92 ± 0.61
S	2.94 ± 0.76	S	0.38 ± 0.10
K	0.09 ± 0.02	K	0.32 ± 0.07
Ca	0.77 ± 0.30	Ca	0.49 ± 0.31
Fe	1.55 ± 0.35	Fe	0.42 ± 0.08
Ti	0.05 ± 0.00	Ti	0.19 ± 0.04

Ash - Summary of all 1978 runs

	80% Load			100% Load		
Element	0% RDF	10% RDF	20% RDF	0% RDF	10% RDF	20% RDF
			Bottom ash			
Al	7.43 ± 1.47	6.18 ± 0.60	5.43 ± 0.43	3.8[a]	5.23 ± 0.21	5.40 ± 0.92
Si	14.7 ± 1.5	21.0 ± 2.9	20.8 ± 1.3	11.0	24.25 ± 1.50	24.76 ± 2.31
S	0.92 ± 0.49	0.64 ± 0.41	0.27 ± 0.10	4.8	0.67 ± 0.24	<0.5 ± 0.0
K	0.75 ± 0.08	0.87 ± 0.03	0.85 ± 0.02	0.45	0.83 ± 0.02	0.95 ± 0.02
Ca	7.44 ± 3.40	7.59 ± 0.77	7.88 ± 1.02	14.1	7.22 ± 0.27	7.88 ± 0.21
Fe	17.4 ± 1.7	8.9 ± 3.0	6.07 ± 1.87	13.8	7.29 ± 0.89	7.26 ± 0.45
Ti	0.48 ± 0.07	0.57 ± 0.11	0.52 ± 0.05	0.16	0.42 ± 0.02	0.46 ± 0.06
			Hopper ash			
Al	8.57 ± 1.48	9.37 ± 0.83	8.10 ± 1.35	8.53 ± 2.26	9.23 ± 1.31	8.73 ± 1.90
Si	15.70 ± 0.95	17.33 ± 0.76	16.13 ± 1.91	16.47 ± 2.95	17.50 ± 2.69	17.90 ± 2.85
S	0.95 ± 0.20	0.65 ± 0.12	0.84 ± 0.15	1.11 ± 0.71	0.85 ± 0.26	0.84 ± 0.09
K	0.96 ± 0.13	1.23 ± 0.06	1.16 ± 0.10	0.95 ± 0.17	1.16 ± 0.08	1.29 ± 0.02
Ca	6.61 ± 3.26	5.55 ± 0.73	7.32 ± 1.39	10.22 ± 3.68	7.82 ± 1.17	9.57 ± 0.33
Fe	17.6 ± 2.94	13.90 ± 2.62	15.0 ± 4.42	14.87 ± 2.80	11.15 ± 3.12	11.79 ± 1.91
Ti	0.59 ± 0.08	0.71 ± 0.07	0.65 ± 0.08	0.53 ± 0.11	0.71 ± 0.05	0.63 ± 0.05

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[a] Only one analysis of 100% load - 0% RDF data available for bottom ash.

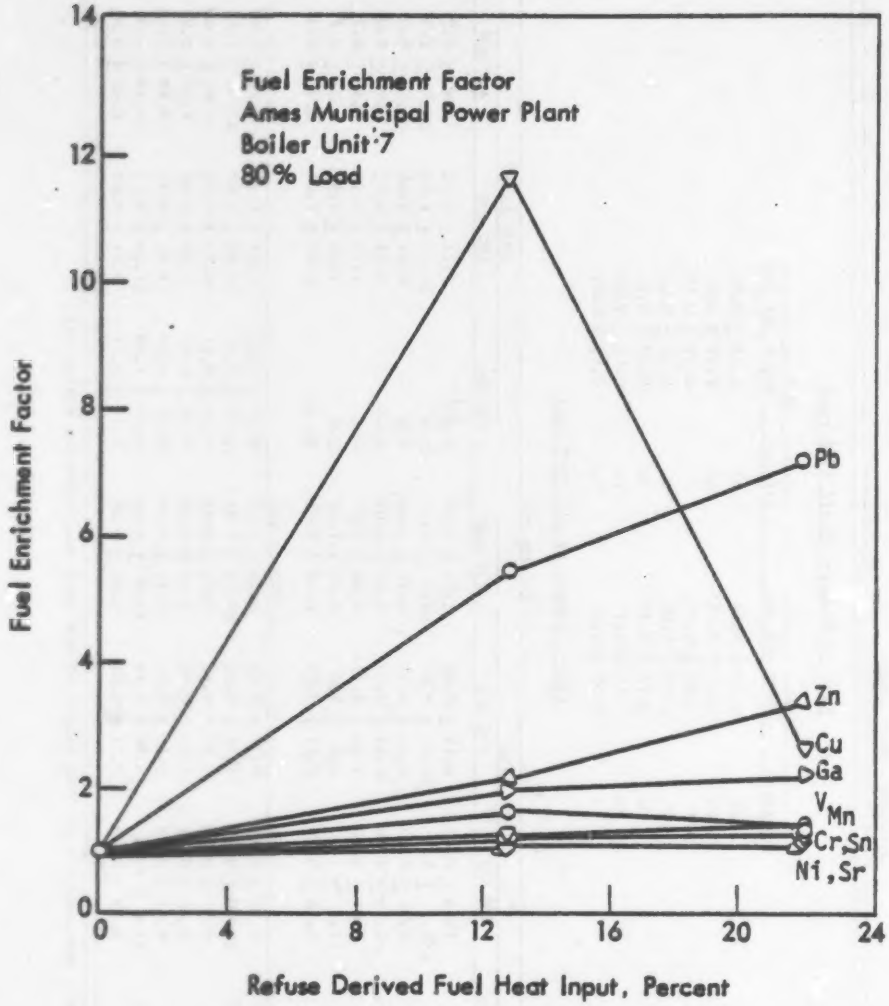

Figure 64. Fuel enrichment factor at 80% load.

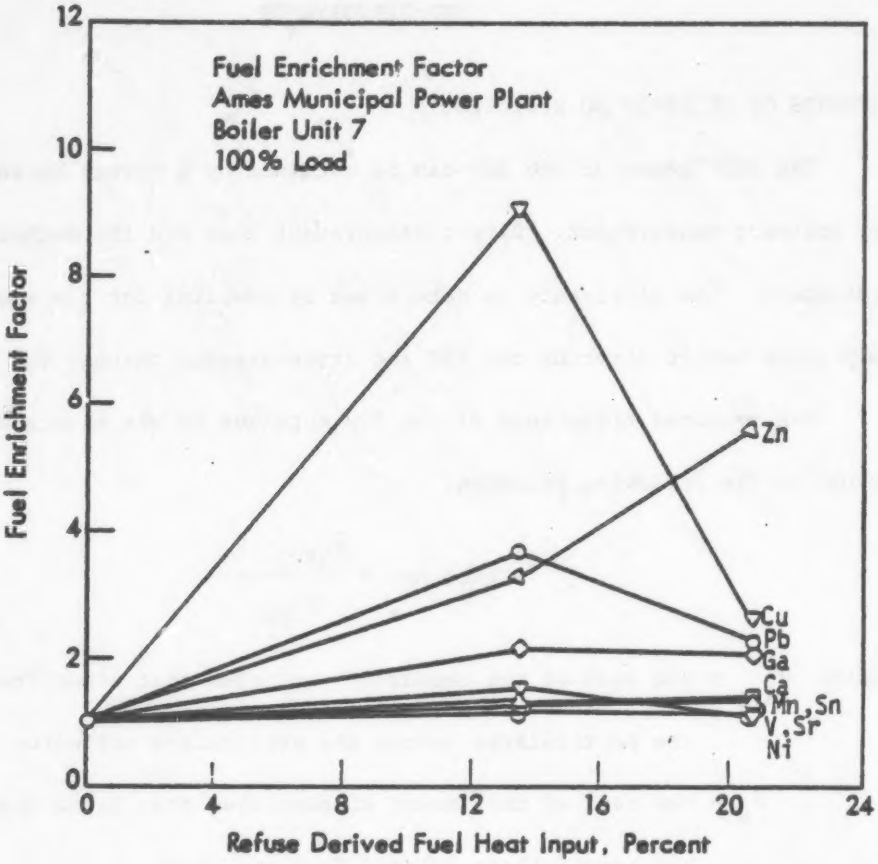

Figure 65. Fuel enrichment factor at 100% load.

SECTION 13

ESP PERFORMANCE

METHODS OF DETERMINING EFFICIENCY

The efficiency of the ESP can be obtained by a direct measurement and an indirect measurement. Direct measurement uses the EPA Method 5 sampling procedure. The efficiency is determined by sampling for the amount of particles before entering the ESP and after passing through the ESP.

The measured efficiency of the ESP obtained by the direct method is given by the following relation:

$$\text{efficiency} = \frac{\dot{P}_{BPC} - \dot{P}_s}{\dot{P}_{BPC}}$$

where $\dot{P}_{BPC}$ = the rate of the amount of particles that enter the ESP which are particulates before the particulate collector

P_s = the rate of the amount of particles that leave the ESP which are particulates emitted from the stack

The result of using this technique was shown in Figure 54 where measured efficiency is given as a function of RDF input to the boiler.

The indirect method involves determining the resistivity of the particles entering the ESP. This is accomplished by using a resistivity probe inserted at the inlet of the ESP at the location shown in Figure 13.

The purpose of the resistivity probe is to create an electric field (simulating the ESP) and to collect entrained flue gas particles in the same manner as the ESP. Once enough of the particles are collected, the resistivity can be determined by two different methods: the point-to-plane method and plane-to-plane method. Both involve increasing the amount of voltage across the collected particulate layer until sparkover occurs. The following equation is used to determine the resistivity of the particles.

$$\rho = \frac{\Delta VA}{IL}$$

where ΔV = the voltage across the dust layer (volts)

I = the amount of current measured (amps)

A = the area of plate that was used to collect the sample (cm^2)

L = the thickness of the dust layer collected (cm)

ρ = the resistivity of the particles sampled (ohm-cm)

Knowing the resistivity of the particles, the efficiency of the ESP can now be found by using the Deutsch-Anderson equation.[12-15]

$$\eta = 1 - \exp - \frac{A}{Q} w$$

where w = migration velocity (ft/sec)

$$\eta = \frac{0.058 F_1 F_2 r p}{\mu}$$

F_1 = peak effective electrical charging field (kV/cm)

F_2 = average electrical field at collecting electrode (kV/cm)

r_p = particle radius (CM)

μ = gas viscosity (poises)

Q = precipitator gas flow rate (ft^3/sec)

A = precipitator collecting electrode area (ft^2)

η = efficiency of collection

White[15] estimated the migration velocity (w) by experimentally obtaining the efficiency of a number of power station precipitators and then estimated the particle migration velocities by substituting the values into the Deutsch-Anderson equation. The corresponding field values for resistivity as a function of the migration velocity were plotted so that the curve would be useful for others needing such information. The curve was used in this study such that the resistivity measurements were needed in order to obtain the migration velocity (w). With the precipitator gas flow measured and the collection electrode area known, the efficiency could be inferred by the Deutsch-Anderson equation.

RESISTIVITY PROBE AND APPARATUS

A Southern Research Institute (SRI) resistivity probe was purchased from the Carborundum Company along with a high voltage power supply (up to 25 kV) and a multimeter. The resistivity probe was used to conduct in situ resistivity tests on ESP unit No. 7.

The resistivity probe was an older model, and certain modifications were made before and during the test schedule to maintain the probe integrity and to ensure proper sampling. A high voltage power supply, an ammeter, a digital temperature indicator, and a spark protector were also used. The spark protector was needed to prevent damage of the equipment when sparkover occurred in the resistivity probe.

Once the resistivity probe was inserted in the duct, the high voltage power supply, digital temperature indicator, and spark protector were connected. The digital temperature indicator allowed the operator to know when the flue gas temperature and cell temperature were within 11°C (20°F) of each other. The spark protector was connected to the ammeter so the ammeter would not be damaged by a sudden surge in current.

MEASUREMENT OF RESISTIVITY

The resistivity probe was designed so that two techniques for obtaining resistivity measurements could be accomplished on the same sample, the point-to-plane method and plane-to-plane method as described in Reference 16. The point-to-plane method can be divided into two parts: point-to-plane first contact and point-to-plane final contact.

The point-to-plane method involves obtaining a "clean plate" voltage-current curve (V-I curve) once the temperature of the cell is within 11°C (20°F) of the temperature of the flue gas. The voltage is initially at zero. It is then increased to 1 kV and the corresponding current is recorded. The voltage is then increased and the procedure continued until sparkover occurs. The resistivity probe is then turned 90 degrees into the flow and dust layer collected. By trial and error, it was found that about

1/2 hr is needed to collect a sufficient amount of sample (about 1 mm thick). After collection of the sample, a "dirty plate" V-I curve is obtained by the same method as before.

The next step is to determine the thickness of the dust layer. The resistivity probe has a 10 mm dial indicator attached to a threaded screw mechanism to allow this measurement. An initial reference or zero reading was taken once the cell had warmed up before the "clean plate" V-I curve readings were taken. The final thickness of the dust layer was determined by an electrical measurement technique. The surface of the dust layer collected is uneven; that is, it is a collection of particles, and different size particles result in peaks on the surface of the collected layer. When the dirty plate V-I curve is taken, the effective distance that the electrical field will "see" is the shortest distance; that is, the distance between the point source of voltage on the probe and the peaks on the dust layer. The point of the first contact was chosen at a current level of 0.005 μA when 100 V was applied across the dust layer. This thickness was used in the point-to-plane first contact method.

A special test series was conducted to help determine what current should be used to determine the final thickness; it was decided that 0.025 μA should be used. With the voltage still at 100 V, the plate was lowered further until a reading of 0.025 μA was reached. This is the point-to-plane "final contact" method. The only difference between the two methods is the thickness used in the resistivity calculation; the voltage, current, and plate area are the same. The voltage used in the equation is the voltage drop interpolated from the V-I curve at a value of current of 1 μA.

The plate is now in the proper position to perform the second measurement of resistivity; the plane-to-plane method. With the plate in direct contact with the dust layer, the voltage is increased in 100 V increments, and the corresponding current is recorded each time. This procedure is repeated until sparkover across the collected dust layer occurs. The resistivity equation values are those recorded just prior to sparkover.

An indirect calculation of the resistivity using the parameters of the ESP can also be determined. The average load voltage and current, the distance between the wires and plates, and the collector plate area were substituted into the resistivity equation. The absolute value of this resistivity has little meaning but the relative value can be plotted along with other data to help correlate trends.

The ESP is divided into an inlet section and an outlet section with corresponding voltage and current meters for each section. A resistivity value was calculated for each section. When used in comparing the ESP data with other data, only the inlet section was used. This was because the majority of the material was collected in the inlet section and the outlet section did not give a good representation of the resistivity of the particles. Resistivity approximated by this technique was consistently higher by an order of magnitude or more than the resistivity probe data.

This data is not presented herein because it is not felt to be reliable or generally applicable. It would allow relative comparisons for only the unit No. 7 ESP at the Ames plant. However, all of the resistivity probe data are felt to be reliable, as well as generally applicable, and is included herein.

The results of the resistivity measurements are shown in Figures 66 through 71. Figure 66 shows the average resistivity values for the experimental runs on the unit No. 7 ESP determined by the point-to-plane methods[14] using both first and final contact points for determination of the collected dust layer thickness. On any given test at least three readings of resistivity were obtained and the average value for each test is plotted in this figure. From this graph, it appears that resistivity increases with increase in both boiler load and RDF. The resistivity values increase from about 10^{10} to 10^{11} ohm-cm.

Figure 67 is a plot of the average resistivity values determined by both the point-to-plane and the plane-to-plane methods. The averages plotted in this figure are the cell averages for each load and each value of RDF used in these experiments. Thus, each point is the average of data for three runs at a given load and value of RDF. With at least three readings per run, each data point plotted represents the average of at least nine separate resistivity measurements. The 1976-1977 data are included for reference but are not felt to be reliable or indicative of typical ESP performance because of difficulties in ESP operation which ultimately required repair during that time span.

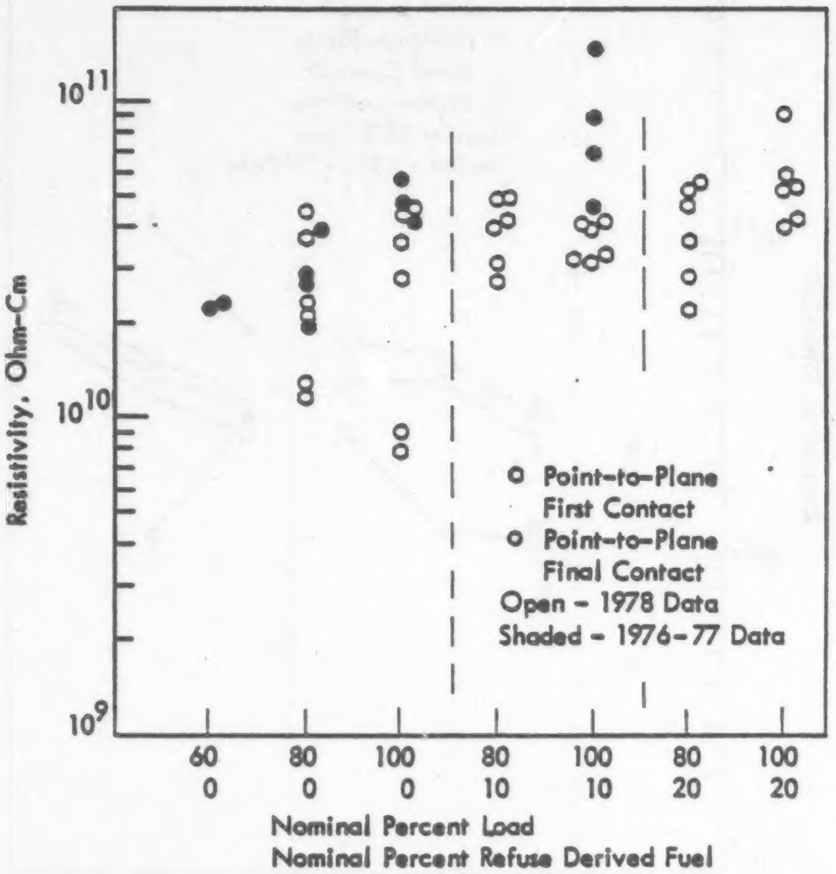

Figure 66. Point-to-plane resistivity measurement data.

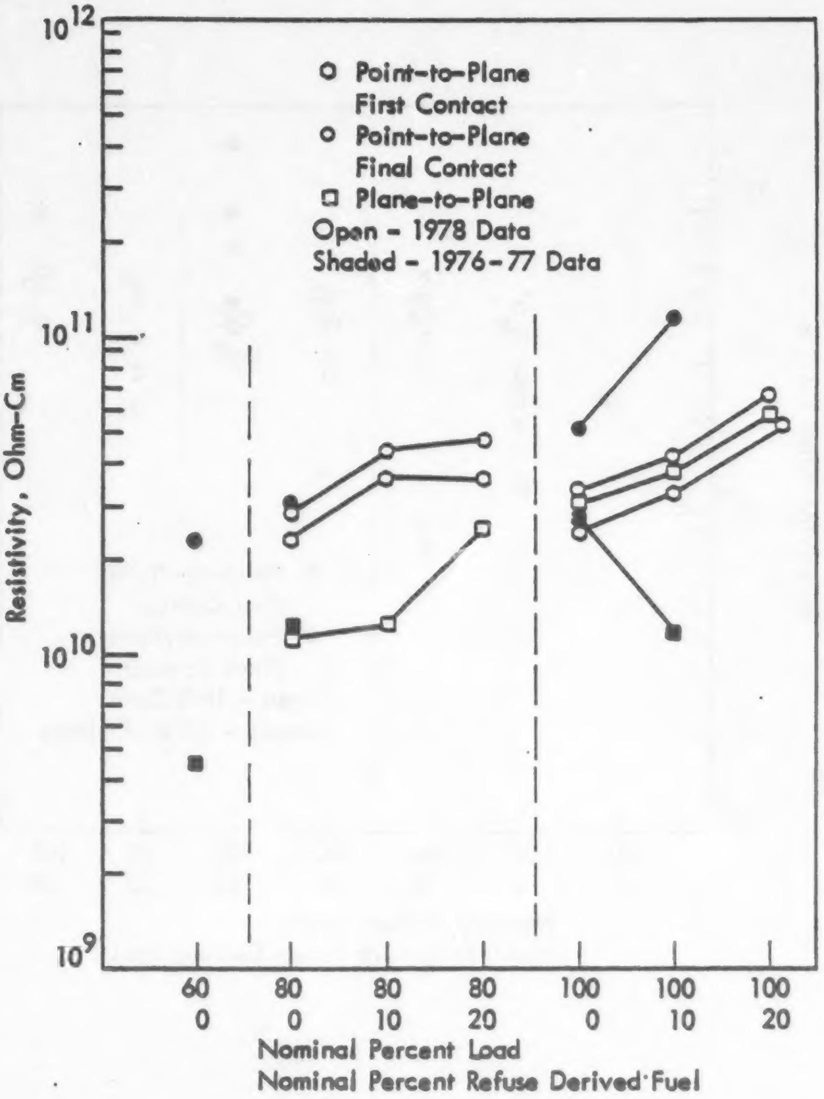

Figure 67. Comparison of point-to-plane and plane-to-plane resistivity measurements.

These difficulties were explained earlier in Section 12 of this report. It should be noted from Figure 67 that the plane-to-plane resistivity values are between the point-to-plane initial contact and point-to-plane final contact values. Thus, the average of the point-to-plane values (initial and final contact) agrees very well with the measured plane-to-plane values of resistivity. From this graph, it is also evident that resistivity increases with increases in both load and RDF. This trend can also be observed in Figure 68 where the average of all of the resistivity determinations have been plotted as a function of both load and RDF.

Figures 69 through 71 show the variation of the plane-to-plane resistivity values, respectively, with temperature, moisture content, and sulfur content of the flue gas. The most consistent trend is that depicted by the dotted line in Figure 69, which indicates that the resistivity increases significantly with increases in temperature. The increase is somewhat load dependent, in that the rate of increase in resistivity is greater with temperature increases that occur at 100% load than at 80% load. Since the particulate grain loading is somewhat dependent on boiler load, this trend indicates the resistivity to be more dependent on temperature at a higher grain loading.

From Figure 70, resistivity appears to generally increase with increased moisture content of the flue gas regardless of boiler load. From Figure 71, resistivity appears to generally decrease with increases in sulfur content of the flue gas (and input fuel) at all loads.

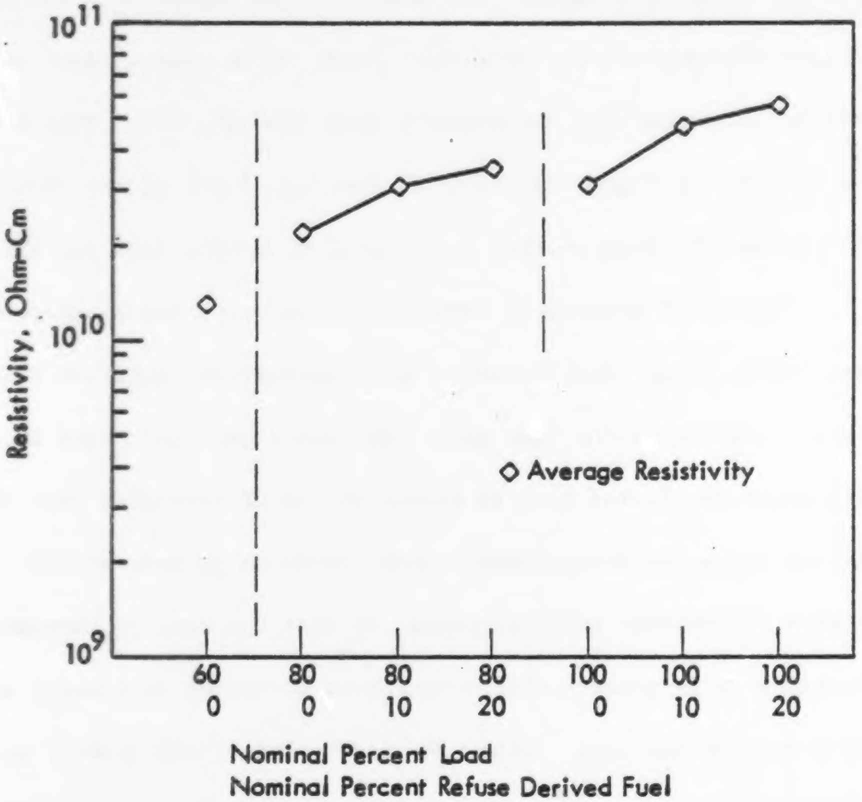

Figure 68. Average resistivity.

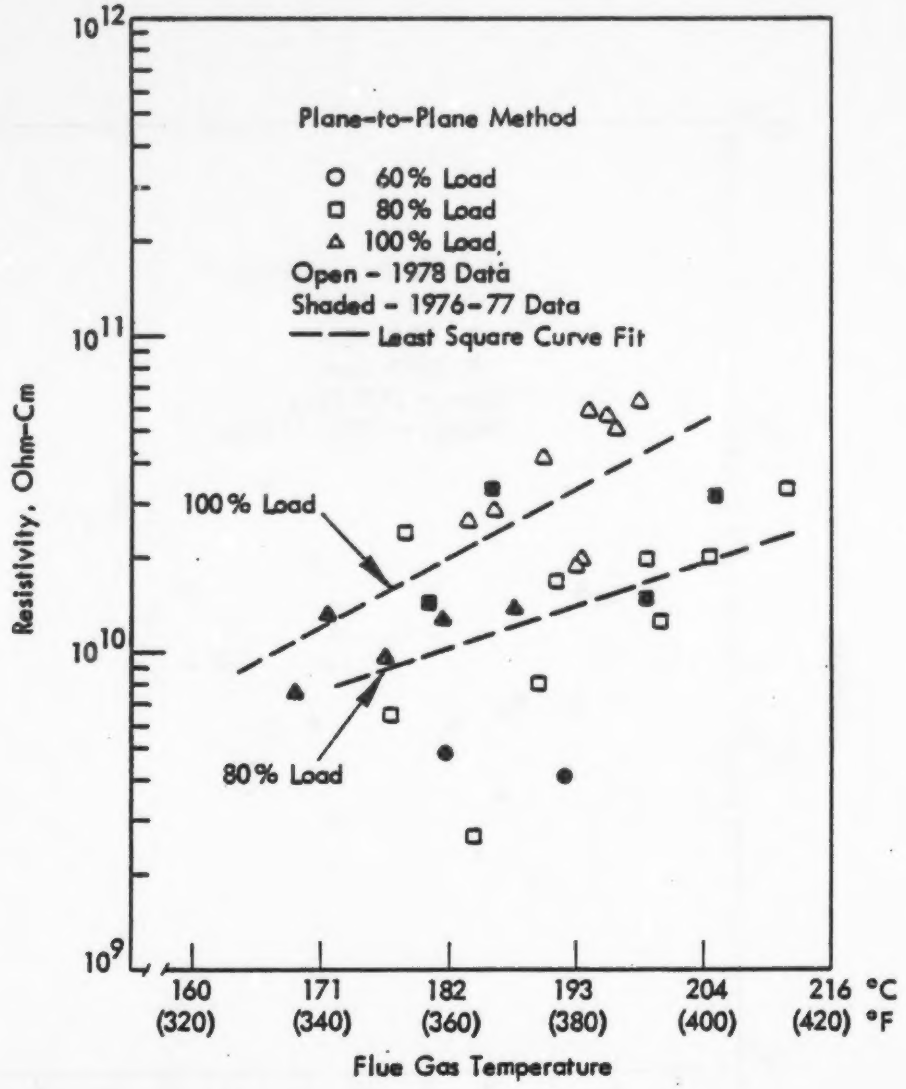

Figure 69. Resistivity versus temperature.

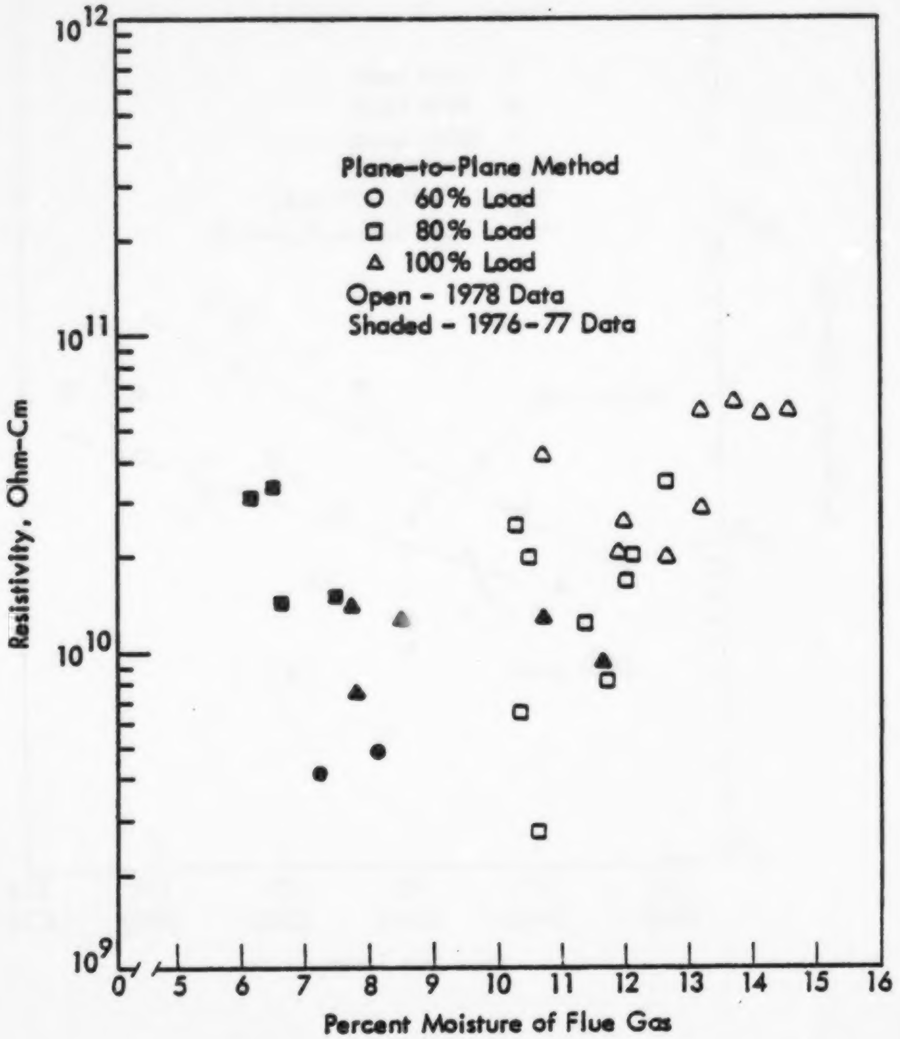

Figure 70. Resistivity versus moisture.

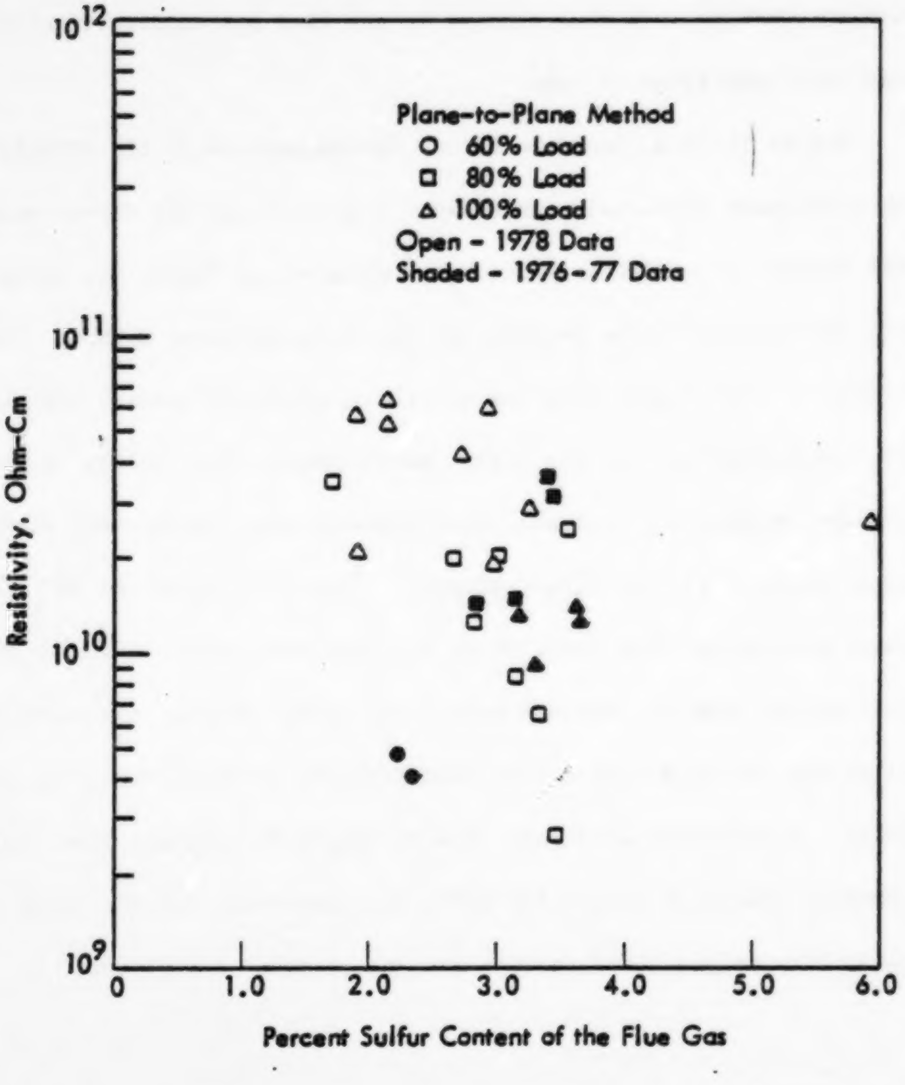

Figure 71. Resistivity versus sulfur.

Although considerable scatter exists in the data of this figure, the data for different load levels can be described with the higher resistivity values occurring at the higher load levels. The decrease in resistivity with an increase in sulfur content in the flue gas apparently occurs at the same rate regardless of load.

Figure 72 is a composite of all determinations of ESP efficiency by the techniques previously described. This includes the direct measurement (EPA Method 5) results as previously indicated in Figure 54, as well as both the point-to-plane methods and the plane-to-plane method. The data plotted in this figure show the excellent agreement between the plane-to-plane determination and the direct measurement. The average of both point-to-plane methods (initial and final contact) also agrees well with the plane-to-plane and the direct methods. Figure 72 shows the ESP efficiency dropping slightly from about 98 to 92% with both boiler load and RDF. Since boiler load is somewhat related to grain loading, the portion of efficiency decrease with boiler load probably reflects the grain loading effect. Comparisons of Figure 68 with Figure 72 indicate that resistivity increases result in slight ESP efficiency decreases for the range of resistivity values (10^{10} to 10^{11} ohm-cm) of these experiments.

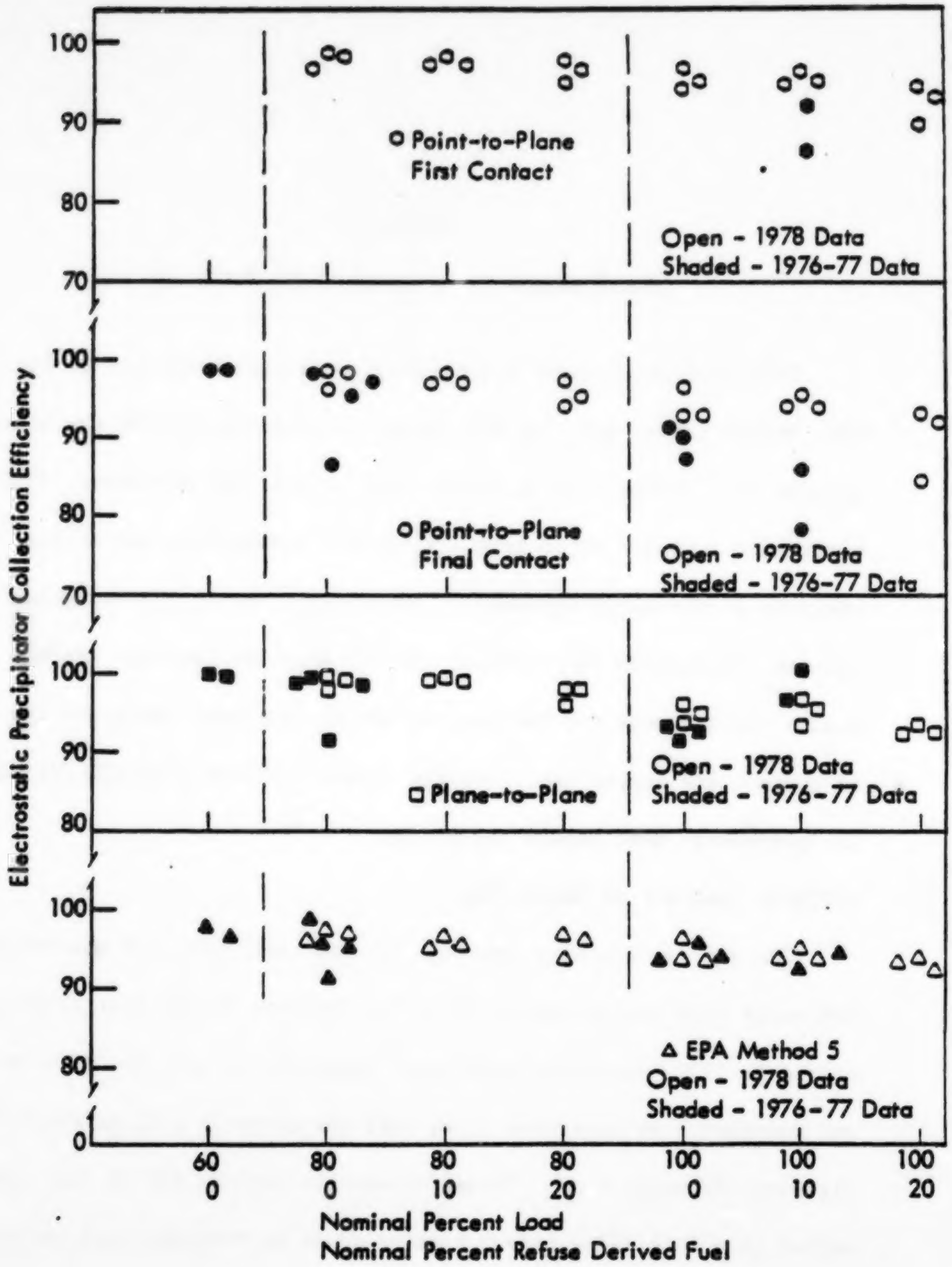

Figure 72. ESP efficiency.

SECTION 14

CHARACTERIZATION OF POWER PLANT FUELS AND ASH

This section provides a more detailed characterization of the coal, RDF, bottom hopper ash, and ESP hopper ash associated with the evaluation of unit No. 7 while burning either coal or coal-RDF mixtures. This characterization includes ultimate analysis, RDF composition and sizing, chemical analysis of the major elements in the mineral ash of the input and output species, evaluation of potential for slagging and fouling, and the ash fusion temperatures for the mineral ash in the input fuels and the output bottom and ESP hopper ash. Average values for each load-RDF firing rate (by percentage heat input) are listed.

ULTIMATE ANALYSIS OF INPUT FUEL

The average ultimate analyses for the coal, RDF, and mass-weighed composite fuel are listed in Table 70. As part of the test program initiated in 1976, coal-only tests were completed on unit No. 7 in November and December. At this time, Iowa coal was mixed in a 50:50 ratio with Big Horn, Wyoming, coal. The difficulty in burning RDF at that time resulted in a long delay before testing could be completed due to completion of the dump grate installation by May 1, 1978. In this time period, the

TABLE 70. ULTIMATE ANALYSIS - AVERAGE VALUES OF COAL, RDF, AND COMPOSITE FUEL

% Load/% RDF		Heating value kJ/kg	Moisture %	Ash %	Carbon %	Hydrogen %	Oxygen %	Sulfur %	Chlorine %	Nitrogen %
1976										
Coal										
60/0	AVG	21,763	18.83	11.71	52.73	2.96	9.92	2.82	0.03	1.00
	σ	1,169.0	4.63	2.49	2.15	0.41	0.97	0.69	0.01	0.00
80/0	AVG	22,194	17.02	12.86	53.30	3.40	8.99	3.45	0.03	1.00
	σ	1,102	2.77	1.76	2.80	0.55	1.26	0.92	0.01	0.00
100/0	AVG	23,939	12.47	15.47	56.97	3.47	7.73	3.83	0.06	1.00
	σ	1,101	2.02	1.01	2.00	0.36	1.97	0.35	0.01	0.00
1978										
Coal										
80/0	AVG	23,618	16.07	8.74	56.73	4.08	10.08	3.11	0.17	1.00
	σ	742	0.60	3.59	1.81	0.23	3.28	0.47	0.18	0.00
80/10	AVG	23,341	17.70	9.11	56.20	3.98	8.71	3.05	0.27	1.00
	σ	428	0.72	1.11	0.70	0.15	0.61	0.38	0.20	0.00
80/20	AVG	23,793	16.10	8.71	57.30	4.01	10.08	2.65	0.14	1.00
	σ	271	1.35	1.39	1.28	0.03	2.12	0.81	0.05	0.00
100/0	AVG	23,496	15.7	10.72	55.73	4.06	10.01	2.70	0.14	1.00
	σ	908	0.95	3.68	2.80	0.29	2.35	1.40	0.09	0.00
100/10	AVG	24,086	16.77	9.26	58.10	3.95	7.83	2.78	0.30	1.00
	σ	61	1.78	1.46	0.44	0.35	3.23	1.14	0.11	0.00
100/20	AVG	23,376	16.97	9.41	55.67	4.03	10.31	2.44	0.18	1.00
	σ	198	1.17	1.53	0.21	0.02	1.35	0.79	0.06	0.00
1978										
RDF										
80/10	AVG	13,938	21.73	11.87	33.23	4.95	27.07	0.37	0.36	0.42
	σ	618	3.89	1.33	1.42	0.11	3.31	0.08	0.09	0.00
80/20	AVG	12,801	24.30	10.28	30.23	4.31	29.63	0.34	0.27	0.42
	σ	328	2.59	0.33	1.97	0.23	0.55	0.03	0.08	0.00
100/10	AVG	14,271	23.30	15.20	32.33	4.64	23.40	0.27	0.48	0.42
	σ	1,602	2.46	2.36	1.55	0.29	2.25	0.02	0.25	0.00
100/20	AVG	12,276	26.87	15.07	26.70	3.92	26.50	1.27	0.27	0.42
	σ	698	1.70	2.66	1.22	0.25	0.72	1.76	0.04	0.00
1978										
Composite fuel										
80/10	AVG	21,461	18.50	9.67	51.57	4.17	12.40	2.52	0.29	0.88
	σ	215	1.30	0.83	0.57	0.10	0.98	0.44	0.17	0.00
80/20	AVG	20,464	18.63	9.15	49.07	4.15	16.07	1.93	0.18	0.83
	σ	741	2.06	1.07	2.57	0.04	0.81	0.52	0.02	0.03
100/10	AVG	21,896	18.23	10.36	52.40	4.10	11.27	2.24	0.34	0.87
	σ	491	0.91	1.38	0.36	0.23	2.92	0.92	0.13	0.01
100/20	AVG	19,571	20.40	11.30	45.77	3.99	15.83	1.70	0.21	0.80
	σ	326	0.26	1.48	1.02	0.08	0.55	0.49	0.05	0.01
1977										
Pre-grate installation										
Coal										
100/10	AVG	21,481	21.90	8.36	51.75	3.38	11.20	2.61	0.06	0.86
	σ	279	1.70	0.98	0.35	0.28	1.85	0.28	0.02	0.01
RDF										
100/10	AVG	11,324	31.10	17.55	27.90	3.78	18.10	0.54	0.62	0.42
	σ	1,920	10.89	2.76	4.67	0.49	2.26	0.04	0.64	0.0
Composite fuel										
100/10	AVG	19,721	23.50	9.90	47.60	3.44	12.40	2.25	0.15	0.77
	σ	226	3.39	0.42	1.41	0.27	1.77	0.27	0.09	0.01

power plant switched to a lower cost low-sulfur coal from Craig, Colorado. Because of this switch in coals, the coal-only tests were repeated so that the effects of burning RDF could be properly assessed.

Examination of Table 70 shows moisture content of coal varying from a low of 15.7% to a high of 17.7% for an average of 16.45%. For 1978, the moisture content of the RDF varied from a low of 21.75% to a high of 26.87% with an average of 24.1%. This implies that a coal with a moderate range of moisture was used and that the impact of burning the higher moisture content fuel will not greatly increase the moisture heat loss. This will be evident in the discussion of the boiler efficiency in Section 15.

The ash content of the coal varied from 8.71 to 10.72% for an average of 9.33%. The mineral ash content of the RDF varied from 10.28 to 15.20% with an average of 13.11%. This average value is lower than that experienced while testing the stoker units and possibly reflects the improvement of the process plant or classifier performance with time.

The heating value of the coal varied from 23,341 to 24,086 kJ/kg with an average of 23,618 kJ/kg. The heating value of the RDF varied from 12,274 to 14,271 kJ/kg with an average value of 13,321 kJ/kg, or 56.40% of the coal average.

An equivalent ultimate analysis composition of the fuel for each load/percentage RDF test condition based on 10^6 kJ fuel heat input was also calculated. This was done to show what increase in fuel constituents would occur for the same heat input. This equivalent ultimate analysis is shown in Table 71. Of interest is the increase in the moisture, mineral ash and chlorine and the decrease in the sulfur. The behavior of the latter two elements corresponds with the results of the stack emissions.

RDF COMPOSITION AND SIZING

The average composition and sizing of the RDF burned is shown in Tables 72 and 73. Most significant is the amount of cardboard, paper, and wood with overall averages of 21.23, 46.47, and 5.10%, respectively. The sizing analysis shows that, on the average, 80.4% of the material was smaller than 38.1 mm. This compares with the original specification that 95% should be 38.1 mm or smaller.

ULTIMATE ANALYSIS OF BOTTOM HOPPER AND ESP HOPPER ASH

Tables 74 and 75 show the ultimate analysis for the bottom hopper and ESP hopper ash. The carbon content in the bottom hopper ash, as discussed previously, decreased with RDF firing and reflects the impact of the dump grate. This decrease in unburned material must be properly assessed because of the increase in bottom ash flow rates. Thus, evaluation of the unburned combustible is performed on a per-hour basis and is discussed under fuel utilization in the next section.

The carbon content of the ESP collector ash shows a slight increase (see Table 75).

CHEMICAL ANALYSIS OF MAJOR ELEMENTS IN ASH

The chemical analysis of the major elements in the mineral ash for the coal, RDF, and mass average composite fuels is given in Table 76.

TABLE 71. FUEL ULTIMATE ANALYSIS COMPOSITION AS A FUNCTION OF HEAT INPUT[a]
(Following elements in terms of kg/kJ)

Load/RDF	Moisture	Ash	Carbon	Hydrogen	Oxygen	Sulfur	Chlorine	Nitrogen
1976								
60/0	8.652	5.381	24.229	1.351	4.558	1.296	0.014	0.460
80/0	7.669	5.785	24.016	1.532	4.051	1.554	0.014	0.460
100/0	5.209	5.209	23.798	1.450	3.237	1.600	0.017	0.460
1978								
80/0	6.804	3.705	24.020	1.728	4.268	1.317	0.072	0.460
80/10	8.620	4.506	24.030	1.943	5.778	1.174	0.135	0.410
80/20	9.103	4.471	23.979	2.028	7.853	0.943	0.088	0.406
100/0	6.682	4.563	23.721	1.720	4.261	1.149	0.060	0.460
100/10	8.326	4.823	23.931	1.872	5.147	1.023	0.155	0.397
100/20	10.424	5.774	23.387	2.039	8.089	0.869	0.107	0.409
1977								
100/10	11.916	5.020	24.137	1.744	6.289	1.141	0.076	0.390

[a] Average values for Load/RDF were converted into equivalent weight per 10^6 kJ of fuel heating value.

TABLE 72. RDF COMPOSITION

Composition (%)	% Load/% RDF							
	80/10 $\bar{x}$	σ	80/20 $\bar{x}$	σ	100/10 $\bar{x}$	σ	100/20 $\bar{x}$	σ
Cardboard	13.58	6.62	28.13	13.29	20.80	14.55	22.42	6.24
Paper	43.48	2.95	40.85	9.16	53.79	12.61	47.75	1.91
Wood	7.67	5.35	4.09	3.62	4.06	2.65	4.59	1.05
Plastic	9.65	1,38	9.96	1.34	4.48	4.86	5.50	1.94
Fe Metal	0.90	1.56	0.06	0.11	0.00	0.00	0.00	0.00
Nonfee Metal	0.76	1.32	0.00	0.00	0.00	0.00	0.00	0.00
Nat'l Organics	2.73	1.46	4.21	1.69	3.67	0.98	4.32	1.69
Cloth	7.40	8.65	1.87	0.74	1.60	0.68	0.48	0.38
Tar	2.18	3.78	0.62	9.81	0.00	0.00	0.00	0.00
Miscellaneous	10.64	2.96	1.07	2.63	10.89	3.07	13.71	1.91
Glass	1.00	0.22	0.39	0.53	0.70	0.26	1.23	0.92

TABLE 73. RDF SIZING ANALYSIS

% Load/% RDF		Larger than 63 mm	% Smaller than (mm) 63	38.1	19.0	9.5	4.8	2.4	Geometric mean diam. mm
80/10	AVG	9.8	90.2	76.2	53.8	31.3	17.8	10.4	15.12
	σ	0.81	0.81	1.19	4.37	6.55	3.4	2.8	1.70
80/20	AVG	9.8	90.2	77.7	51.6	29.5	15.3	8.8	15.79
	σ	1.6	1.6	2.9	9.2	3.1	1.5	0.35	1.39
100/10	AVG	9.2	90.8	80.2	46.7	21.6	14.2	8.0	17.10
	σ	3.6	3.6	3.4	6.8	3.2	2.3	1.6	0.44
100/20	AVG	3.4	96.6	87.4	44.1	29.9	18.4	11.2	14.52
	σ	1.7	1.7	2.8	6.3	6.2	2.9	1.2	1.75

TABLE 74. ULTIMATE ANALYSIS OF BOTTOM HOPPER ASH

% Load/% RDF		Heating value kJ/kg	Carbon %	Hydrogen %	Sulfur %	Mineral ash %
1976						
60/0	AVG	4,017	7.51	0.87	2.58	89.04
	σ	2,329	4.90	0.56	1.12	4.32
80/0	AVG	3,040	5.46	1.19	3.59	89.76
	σ	398	1.24	1.16	1.40	1.20
100/0	AVG	3,077	5.53	0.49	5.56	88.41
	σ	751	0.95	0.15	3.83	4.67
1978						
80/0	AVG	1,950	4.62	0.20	1.06	94.12
	σ	373	0.88	0.07	0.86	1.24
80/10	AVG	1,127	2.05	0.22	1.35	96.38
	σ	91	0.32	0.03	1.38	1.16
80/20	AVG	1,610	3.10	0.37	0.31	96.22
	σ	347	0.72	0.08	0.04	0.78
100/0	AVG[a]	3,590	6.61	0.38	8.97	84.04
	σ					
100/10	AVG	3,690	1.55	0.09	0.19	98.18
	σ	2,330	0.29	0.13	0.06	0.47
100/20	AVG	1,061	2.08	0.23	0.25	97.55
	σ					

[a] Composite sample.

TABLE 75. ULTIMATE ANALYSIS OF COLLECTOR (ESP) ASH

% Load/% RDF		Heating value (kJ/kg)	Carbon (%)	Hydrogen (%)	Sulfur (%)	Mineral ash (%)
1976						
60/0	AVG	794	0.79	0.27	1.52	97.42
	σ	159	0.19	0.08	0.25	0.47
80/0	AVG	1,307	0.95	0.60	1.35	97.10
	σ	368	0.27	0.25	0.28	0.57
100/0	AVG	1,650	1.87	0.63	1.35	96.15
	σ	689	1.151	0.30	0.18	1.47
1978						
80/0	AVG	836	1.85	0.10	0.70	97.34
	σ	171	0.55	0.02	0.34	0.54
80/10	AVG	1,047.0	2.43	0.11	0.69	96.76
	σ	143	0.35	0.01	0.13	0.46
80/20	AVG	1,177.0	2.54	0.17	0.86	96.44
	σ	61.0	0.05	0.05	0.14	0.14
100/0	AVG	885	1.92	0.10	0.55	97.43
	σ	238	0.78	0.02	0.41	0.93
100/10	AVG	1,049	2.41	0.11	0.82	96.66
	σ	188	0.49	0.01	0.21	0.59
100/20	AVG	1,043	2.40	0.11	0.83	96.66
	σ	127	0.40	0.02	0.13	0.31
1977						
224		1,900	5.00	0.08	1.13	93.79
225		1,630	4.37	0.05	0.94	94.64

TABLE 76. CHEMICAL ANALYSIS OF MAJOR ELEMENTS OF MINERAL ASH FOR COAL, RDF, AND FUEL MIXTURE

% Load/% RDF		SO_3 %	Al_2O_3 %	SiO_2 %	TiO_2 %	K_2O %	CaO %	Fe_2O_3 %	Na_2O %	MgO %	P_2O_5 %
1976											
Coal											
60/0	AVG	N/A	30.58	27.53	0.638	1.625	10.66	24.72	1.689	1.630	1.085
	σ		1.23	0.81	0.066	0.136	1.55	0.92	1.136	0.810	0.464
80/0	AVG	N/A	28.54	30.28	0.659	1.874	9.89	25.50	1.154	1.237	0.862
	σ		3.37	2.47	0.080	0.448	0.85	2.57	0.682	0.408	0.127
100/0	AVG	N/A	30.40	30.42	0.554	2.567	10.11	23.48	0.647	1.028	0.794
	σ		1.56	1.47	0.231	0.402	0.31	1.08	0.150	0.220	0.132
1978											
Coal											
80/0	AVG	11.5	19.2	34.0	0.99	1.12	2.97	26.6	1.13	0.76	0.89
	σ	4.7	3.6	4.7	0.06	0.46	1.79	3.9	0.39	0.01	0.19
80/10	AVG	9.3	16.1	38.4	1.10	1.41	3.43	25.0	1.35	0.86	0.73
	σ	0.9	0.3	3.4	0.10	0.42	0.24	3.7	0.37	0.06	0.06
80/20	AVG	10.6	18.0	35.5	1.01	1.34	5.52	23.7	1.40	0.80	1.03
	σ	4.5	4.5	5.4	0.09	0.42	3.32	6.8	0.27	0.09	0.38
RDF											
80/10	AVG	6.19	22.8	51.4	2.06	1.44	6.23	4.65	1.40	1.86	0.79
	σ	1.04	1.6	3.4	0.29	0.25	0.57	0.30	0.54	0.22	0.09
80/20	AVG	4.03	20.1	52.7	1.83	1.68	5.22	9.11	1.96	1.74	0.76
	σ	0.30	1.6	6.5	0.32	0.03	1.33	6.81	0.16	0.31	0.11
Fuel											
80/10	AVG	8.71	17.43	41.01	1.29	1.41	3.98	20.98	1.36	1.05	0.74
	σ	0.52	0.54	2.02	0.12	0.38	0.26	2.91	0.38	0.09	0.06
80/20	AVG	8.43	18.57	41.10	1.27	1.45	5.39	19.11	1.58	1.09	0.97
	σ	2.81	2.52	1.22	0.10	0.27	2.52	5.06	0.15	0.14	0.28
Coal											
100/0	AVG	13.71	1.79	37.1	0.94	1.37	4.84	21.4	0.85	0.89	0.50
	σ	5.95	1.7	1.2	0.41	0.44	0.76	4.9	0.11	0.33	0.05
100/10	AVG	12.22	17.8	37.3	1.03	1.40	4.39	22.2	1.23	1.00	0.67
	σ	3.97	5.1	9.2	0.04	0.40	1.28	7.44	0.29	0.20	0.26
100/20	AVG	12.17	20.3	36.3	1.00	1.65	4.11	18.23	1.05	0.87	0.78
	σ	1.65	1.1	6.8	0.0	0.01	0.43	7.20	0.16	0.08	0.14

(continued)

TABLE 76. (continued)

% Load/% RDF	SO_3 %	Al_2O_3 %	SiO_2 %	TiO_2 %	K_2O %	CaO %	Fe_2O_3 %	Na_2O %	MgO %	P_2O_5 %
RDF										
100/10 AVG	7.39	19.3	49.3	2.21	1.67	8.70	4.75	2.00	1.81	0.62
σ	2.11	2.6	2.9	0.44	0.03	1.06	2.11	0.11	0.24	0.03
100/20 AVG	7.64	19.3	54.4	1.73	1.29	8.05	1.99	1.78	0.52	7.64
σ	1.58	0.2	2.6	0.09	0.70	0.60	0.06	0.15	0.26	1.58
Fuel										
100/10 AVG	11.17	18.13	39.84	1.29	1.47	5.36	18.44	1.40	1.18	0.66
σ	3.59	3.49	7.92	0.12	0.30	1.14	5.75	0.23	0.20	0.21
100/20 AVG	10.61	19.97	42.60	1.25	1.53	5.46	13.21	1.37	1.19	0.69
σ	1.44	0.74	4.65	0.03	0.24	0.44	4.62	0.09	0.04	0.08
All 1978 Coal										
AVG	11.58	18.22	36.43	1.01	1.38	4.21	22.85	1.17	0.86	0.77
σ	1.51	1.42	1.54	0.05	0.17	0.93	2.94	0.20	0.83	0.18
All 1978 RDF										
AVG	6.31	20.38	51.95	1.96	1.52	7.05	5.13	1.79	1.48	2.45
σ	1.64	1.66	2.15	0.22	0.19	1.61	2.95	0.27	0.64	3.46

The chemical analyses for the mineral ash, for the bottom hopper ash, and for the ESP hopper ash are listed in Tables 77 and 78. Examination of the tabulated values for the chemical analysis of the coal indicates a bituminous-type ash, whereas the RDF ash is considered a lignite type. The mineral type ash is considered of the bituminous type if the concentration of Fe_2O_3 is greater than the sum of the CaO + MgO constituents, whereas the opposite is true for lignite-type ash.

The bottom hopper ash samples for the 1978 coal tests at 100% load and 0% RDF were inadvertently mixed at the laboratory, so only a single sample was available for analysis. The resultant chemical analysis of the ash indicates constituent compositions that are completely out of proportion. This includes sulfur at 8.97%, Fe_2O_3 at 28.2%, and SiO_2 at 13.8%. The only possible explanation is that some highly pyritic coal rejected by the pulverizer and first sluiced into the boiler hopper ultimately was mixed in. Normal sluicing procedure would entail sluicing of pyrite rejects into the boiler hopper and then removing them out to the ash pond along with the main ash. During boiler testing, pyrite sluicing was not allowed.

The most significant differences between the mineral ash for the coal and the RDF for 1978 are in the silicon oxide, ferric oxide, and calcium oxide concentrations. The overall SiO_2 average for the coal ash was 36.43%; and for the RDF ash, 51.95%. The average Fe_2O_3 for the mineral ash in coal was 22.85%; and for RDF, 5.13%. The average CaO in coal was 4.21%; and for the RDF ash, 7.05%. The average Na_2O concentration in the coal ash was

TABLE 77. CHEMICAL ANALYSIS OF MAJOR ELEMENTS OF MINERAL ASH IN BOTTOM HOPPER ASH[a]

% Load/% RDF		SO_3 %	Al_2O_3 %	SiO_2 %	TiO_2 %	K_2O %	CaO %	Fe_2O_3 %	Na_2O %	MgO %	P_2O_5 %
1976											
60/0	AVG	N/A	13.94	24.12	0.5799	1.269	15.48	39.77	0.9796	1.835	1.10
	σ		0.0	0.0	0.0	0.0	0.0	0.0	0.5259	0.483	0.13
80/0	AVG	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.5985	1.507	0.806
	σ								0.2630	0.459	0.095
100/0	AVG	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.4134	0.9949	0.901
	σ								0.0866	0.2444	0.2118
1978											
80/0	AVG	3.55	17.6	39.0	1.01	1.61	4.96	29.8	1.32	0.71	0.80
	σ	2.23	5.3	1.0	0.03	0.07	2.39	1.92	0.38	0.01	0.20
80/10	AVG	2.31	19.3	49.6	1.33	1.63	5.32	16.2	1.97	1.39	0.60
	σ	1.29	4.4	8.1	0.19	0.02	0.71	5.33	0.28	0.22	0.04
80/20	AVG	2.31	21.1	53.6	1.05	0.94	4.12	8.88	5.08	1.76	0.85
	σ	0.14	1.0	0.9	0.03	0.01	0.30	1.19	0.10	0.09	0.11
100/0	A[illegible]	15.8	6.46	13.8	0.08	0.41	19.2	28.2	1.01	13.6	0.34
	σ	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100/10	AVG	2.39	11.5	55.2	0.97	0.74	11.2	11.07	4.48	1.54	0.45
	σ	0.72	1.8	0.7	0.12	0.03	1.04	1.59	0.36	0.62	0.09
100/20	AVG	1.30	10.9	55.3	1.06	0.82	11.03	11.27	4.46	2.26	0.52
	σ	0.48	0.38	1.2	0.15	0.01	0.12	1.32	0.48	0.35	0.09

a/ Composite bottom ash sample.

TABLE 78. CHEMICAL ANALYSIS OF MAJOR ELEMENTS OF MINERAL ASH OF ESP HOPPER ASH

% Load/% RDF		SO_3 %	AL_2O_3 %	SiO_2 %	TiO_2 %	K_2O %	CaO %	Fe_2O_3 %	Na_2O_3 %	MgO %	P_2O_5 %
1976											
60/0	AVG	N/A	27.40	26.40	0.7102	2.016	11.22	27.55	1.779	1.835	1.085
	σ		0.95	1.27	0.0675	0.225	0.80	1.07	0.865	0.622	0.173
80/0	AVG	N/A	26.72	25.84	0.6766	2.115	12.83	28.70	1.127	1.124	1.008
	σ		0.70	0.19	0.0879	0.129	0.34	0.24	0.910	0.426	0.092
100/0	AVG	N/A	27.23	25.90	0.6124	2.115	13.25	26.70	0.9705	1.293	1.069
	σ		1.36	1.14	0.0426	0.254	2.58	1.71	0.1886	0.191	0.161
1978											
80/0	AVG	2.04	19.7	39.3	1.15	1.67	4.68	27.1	1.56	0.75	0.86
	σ	0.97	1.6	3.9	0.03	0.03	2.24	5.23	0.02	0.12	0.10
80/10	AVG	2.15	20.6	43.7	1.35	1.69	5.17	21.7	1.65	1.10	0.76
	σ	0.28	1.4	2.2	0.10	0.0	1.42	3.21	0.03	0.02	0.05
80/20	AVG	2.16	17.9	46.3	1.33	1.70	6.13	19.7	1.64	1.15	0.83
	σ	0.42	1.7	1.6	0.02	0.03	0.83	2.1	0.03	0.04	0.17
100/0	AVG	3.23	17.0	41.5	1.24	1.63	6.99	24.8	1.56	0.80	0.73
	σ	1.60	4.3	6.5	0.11	0.06	2.02	5.6	0.05	0.22	0.24
100/10	AVG	2.38	19.9	47.4	1.27	1.66	5.94	18.2	1.64	1.27	0.75
	σ	0.61	4.3	4.7	0.09	0.04	0.80	6.2	0.06	0.32	0.02
100/20	AVG	2.43	19.3	44.1	1.32	1.65	6.65	19.5	1.67	1.10	0.88
	σ	0.32	1.0	4.1	0.05	0.01	0.43	3.2	0.04	0.05	0.13
1977											
100/10	AVG[a]		10.94	30.38	1.27	1.40	9.00	28.17	1.16	2.04	0.665
	σ										

[a] Single analysis.

1.17%; and in the RDF ash, 1.79%. The impact of these differences will be considered in the discussion of the calculated slagging and fouling indices.

Review of the bottom hopper ash chemical analysis in Table 77 reveals an increase in the SiO_2 concentration with increase in percentage RDF firing. An unusual factor is that this concentration is higher than that for the fuel concentration. Examination of the SiO_2 concentration in the ESP hopper ash indicates the same behavior. Especially significant is the fact that the SiO_2 concentrations are higher than that for the fuel input. It should be remembered that ash is also adhering to the furnace water wall (as slag) and superheater tube banks. No samples of this material were collected, so a complete material balance is not possible.

Another unusual result is the higher concentrations of Na_2O found in the bottom hopper ash. Normally, the sodium vaporizes and recondenses as the gases are cooled in passing through the boiler convection passes. One possible explanation is that the physical contact due to the mixing of the pulverized coal particles and the injected RDF results in a new burning behavior. Examination of the Na_2O in the ESP hopper ash indicates concentrations slightly higher than that for the fuel input.

SLAGGING AND FOULING INDICES

Potential slagging/fouling problems are evaluated by relationships that involve the major chemical elements of mineral ash expressed in oxide form. These are:

Slagging index = (base/acid) x (% sulfur on dry coal basis)

Fouling index = (base/acid) x (% Na_2O)

where

$$\text{Base/acid} = \frac{Na_2O + K_2O + Fe_2O_3 + CaO + MgO}{SiO_2 + Al_2O_3 + TiO_2}$$

The base/acid ratio, the slagging index, and the fouling index were calculated for the coal, RDF, mass-weighed fuel mixture, the bottom hopper ash, and the ESP collector ash. These 1976 and 1978 test values are listed in Tables 79 and 80.

Potential difficulty of slagging in the furnace wall section or fouling in the boiler convection passes is based on the following criteria:

Slagging type	Slagging index
Low	Less than 0.6
Medium	0.6 to 2.0
High	2.0 to 2.6
Severe	Greater than 2.6

Fouling type	Fouling index
Low	Less than 0.2
Medium	0.2 to 0.5
High	0.5 to 1.0
Severe	Greater than 1.0

The coal used in the 1976 tests was generally a mixture of Iowa-Wyoming (Big Horn) coals. The potential for high to severe slagging is indicated due to the calculated range of index values from 2.319 to 2.705. Likewise, the potential for medium to severe fouling is indicated. Furnace wall blowers are located immediately above and below the burner levels.

TABLE 79. BASE/ACID RATIO AND SLAGGING AND FOULING INDICES FOR COAL, BOTTOM HOPPER ASH AND PRECIPITATOR (ESP) COLLECTOR ASH - 1976

		Coal			Bottom hopper ash			ESP collector ash		
% Load/% RDF		Base/acid ratio	Fouling index	Slagging index	Base/acid ratio	Fouling index	Slagging index	Base/acid ratio	Fouling index	Slagging index
1976										
60/0	AVG	0.6893	1.1669	2.372	1.556	2.350	4.777	0.8165	1.478	1.233
	σ	0.0457	0.8185	0.450	-	-	-	0.0691	0.805	0.143
80/0	AVG	0.6722	0.8566	2.319	N/A	N/A	N/A	0.8591	1.083	1.095
	σ	0.1060	0.8052	0.510				0.0249	0.960	0.264
100/0	AVG	0.6165	0.3982	2.705	N/A	N/A	N/A	0.8422	0.8133	1.1447
	σ	0.0111	0.0894	0.307				0.0663	0.1440	0.2420

TABLE 80. BASE/ACID RATIO AND SLAGGING AND FOULING INDICES FOR COAL, RDF, COMPOSITE FUEL, BOTTOM HOPPER ASH AND PRECIPITATOR (ESP) COLLECTOR ASH - 1978

		Coal			RDF			Fuel			Bottom hopper ash			ESP collector ash		
% Load/% RDF		Base/acid ratio	Fouling index	Slagging index	Base/acid ratio	Fouling index	Slagging index	Base/acid ratio	Fouling index	Slagging index	Base/acid ratio	Fouling index	Slagging index	Base/acid ratio	Fouling index	Slagging index
80/0	AVG	0.600	0.673	2.235	-	-	-	0.600	0.673	2.235	0.675	0.916	0.785	0.599	0.931	0.418
	σ	0.041	0.220	0.453	-	-	-	0.041	0.220	0.453	0.140	0.383	0.749	0.107	0.154	0.224
80/10	AVG	0.580	0.764	2.193	0.204	0.292	0.0725	0.484	0.643	1.50	0.385	0.740	0.494	0.478	0.789	0.330
	σ	0.089	0.157	0.745	0.018	0.139	0.0061	0.055	0.133	0.441	0.110	0.122	0.470	0.056	0.096	0.058
80/20	AVG	0.611	0.867	2.051	0.270	0.519	0.105	0.471	0.752	1.13	0.275	1.396	0.085	0.464	0.762	0.399
	σ	0.157	0.335	1.193	0.094	0.134	0.047	0.069	0.178	0.468	0.010	0.043	0.011	0.037	0.058	0.083
100/0	AVG	0.524	0.437	1.600	-	-	-	0.524	0.437	1.600	2.964	2.994	26.6 a/	0.625	0.966	0.306
	σ	0.071	0.114	0.618				0.071	0.114	0.618	-	-	-	0.240	0.340	0.230
100/10	AVG	0.578	0.723	2.189	0.267	0.534	0.127	0.492	0.686	1.47	0.429	1.911	0.082	0.430	0.703	0.371
	σ	0.266	0.444	1.606	0.016	0.051	0.028	0.187	0.307	0.994	0.046	0.059	0.031	0.143	0.218	0.190
100/20	AVG	0.461	0.467	1.452	0.224	0.444	0.100	0.361	0.488	0.776	0.444	1.974	0.112	0.475	0.790	0.401
	σ	0.179	0.119	1.015	0.032	0.051	0.017	0.105	0.112	0.400	0.024	0.122	0.034	0.076	0.110	0.126

a/ Non-representative composite bottom ash sample.

Long penetration soot blowers are also used between the primary and secondary superheater tube banks.

The coal used in the 1978 tests was a mixture of Iowa-Colorado (Craig) coals. Again, the potential for medium to high slagging is indicated. Likewise, the potential for medium to high fouling is indicated. Using the same index, a lower fouling and slagging behavior is indicated. The calculated indices based on a mass-average fuel indicate a drop in the potential for slagging.

Actual operation experience encountered in the combined coal-RDF firing resulted in an increase in upper furnace wall slagging especially along the back wall. It appeared that the injected RDF did not penetrate the tangential fireball but was carried around the periphery. This flow pattern would result in the lighter material impacting on the upper wall. Likewise, the heavier material would fall in its circular travel near the furnace wall and be deposited on the dump grate in the opposite corner. This behavior was especially noticeable if RDF was injected only in one corner. A pile of ash would build up in the opposite corner down on the grate.

ASH FUSION TEMPERATURES

The average ash fusion temperatures for each level of the mineral ash in the coal, RDF, bottom hopper ash, and ESP hopper ash are listed in Table 81. These ash fusion temperatures are called initial deformation temperature (IT), softening temperature (ST), hemispherical temperature

TABLE 81. ASH FUSION TEMPERATURES FOR MINERAL ASH IN COAL, RDF, BOTTOM HOPPER AND ESP HOPPER ASH

% Load/% RDF			Reducing atmosphere				Oxidizing atmosphere			
			IT	ST	HT	FT	IT	ST	HT	FT
1976										
60/0	Coal	AVG	1117	1125	1132	1151	1251	1260	1269	1278
		σ	27.68	29.72	33.87	54.05	25.06	25.53	27.3	30.75
	Refuse	AVG	-	-	-	-	-	-	-	-
		σ	-	-	-	-	-	-	-	-
	Grate ash	AVG	1125	1132	1140	1154	1263	1274	1284	1293
		σ	36.04	33.50	36.53	29.67	16.17	9.85	6.35	5.69
	Coll. ash	AVG	1134	1143	1158	1172	1282	1288	1293	1297
		σ	30.41	35.35	48.82	60.62	14.36	18.23	22.5	23.52
80/0	Coal	AVG	1116	1130	1148	1173	1227	1237	1257	1280
		σ	31.09	38.62	43.82	40.64	42.30	44.76	54.32	67.62
	Refuse	AVG	-	-	-	-	-	-	-	-
		σ	-	-	-	-	-	-	-	-
	Grate ash	AVG	1073	1084	1092	1108	1230	1240	1251	1264
		σ	25.08	27.77	28.33	42.49	20.8	22.42	24.89	26.52
	Coll. ash	AVG	1107	1116	1134	1163	1262	1273	1287	1300
		σ	42.67	44.73	48.25	42.39	26.26	25.62	25.96	23.61
100/0	Coal	AVG	1123	1133	1141	1152	1243	1251	1258	1265
		σ	17.35	13.23	8.62	8.62	25.42	23.46	21.00	19.63
	Refuse	AVG	-	-	-	-	-	-	-	-
		σ	-	-	-	-	-	-	-	-
	Grate ash	AVG	1093	1098	1103	1107	1182	1190	1195	1201
		σ	22.50	22.07	22.72	22.48	77.27	74.39	73.82	73.82
	Coll. ash	AVG	1125	1136	1147	1164	1232	1245	1258	1281
		σ	3.46	3.46	3.46	6.35	28.0	25.06	25.06	16.8
1978										
80/0	Coal	AVG	1162	1175	1184	1206	1290	1303	1314	1336
		σ	36.8	45.0	46.9	39.5	43.4	51.6	51.6	48.1
	Refuse	AVG	-	-	-	-	-	-	-	-
		σ	-	-	-	-	-	-	-	-
	Grate ash	AVG	1110	1121	1132	1155	1221	1236	1253	1264
		σ	38.1	38.8	34.8	20.1	49.2	56.9	66.1	71.7
	Coll. ash	AVG	1136	1147	1162	1195	1301	1312	1326	1342
		σ	11.53	11.5	8.62	37.1	19.6	19.6	25.4	31.6
80/10	Coal	AVG	1149	1162	1175	1225	1301	1330	1371	1386
		σ	45.5	42.2	44.9	61.3	34.8	35.7	34.8	32.5
	Refuse	AVG	1154	1166	1184	1219	1171	1188	1206	1234
		σ	14.7	16.5	11.5	8.62	14.7	11.0	14.1	16.8
	Grate ash	AVG	1114	1121	1138	1147	1199	1208	1221	1232
		σ	33.7	30.8	24.4	26.3	20.1	17.4	11.0	9.81
	Coll. ash	AVG	1128	1143	1151	1201	1232	1265	1258	1269
		σ	33.7	27.5	33.1	36.8	73.5	70.1	71.3	71.3

(continued)

TABLE 81. (concluded)

% Load/% RDF			Reducing atmosphere				Oxidizing atmosphere			
			IT	ST	HT	FT	IT	ST	HT	FT
80/20	Coal	AVG	1158	1169	1181	1195	1286	1306	1332	1354
		σ	30.4	30.4	30.8	37.1	39.2	42.3	52.7	50.0
	Refuse	AVG	1126	1136	1143	1162	1160	1175	1186	1199
		σ	30.9	31.05	27.5	35.2	24.4	22.7	16.8	9.81
	Grate ash	AVG	1131	1138	1145	1152	1169	1177	1184	1193
			16.8	20.1	22.9	26.3	33.1	36.8	39.5	45.5
	Coll. ash	AVG	1125	1140	1152	1173	1229	1242	1256	1267
		σ	22.7	17.8	16.2	16.2	16.2	12.7	16.8	11.9
100/0	Coal	AVG	1234	1255	1269	1310	1254	1267	1289	1316
		σ	27.5	20.1	19.6	33.9	25.4	22.9	14.4	25.4
	Refuse	AVG	-	-	-	-	-	-	-	-
		σ	-	-	-	-	-	-	-	-
	Grate ash	AVG	1127	1132	1138	1143	1188	1193	1199	1216
		σ	0	0	0	0	0	0	0	0
	Coll. ash	AVG	1129	1138	1149	1164	1197	1208	1219	1230
		σ	58.6	61.8	67.2	74.2	100.2	106	112	117
100/10	Coal	AVG	1227	1239	1260	1277	1293	1304	1323	1334
		σ	60.2	62.3	64.2	61.8	11.0	11.5	17.4	11.5
	Refuse	AVG	1138	1147	1162	1188	1147	1156	1178	1204
		σ	0	3.46	11.5	30.9	3.21	6.35	16.8	36.3
	Grate ash	AVG	1091	1108	1123	1167	1108	1153	1184	1210
		σ	2.89	8.62	6.35	22.9	17.8	6.35	8.19	20.1
	Coll. ash	AVG	1147	1158	1169	1204	1221	1236	1253	1288
		σ	45.1	45.1	45.1	43.8	52.9	51.4	52.0	43.4
100/20	Coal	AVG	1278	1292	1310	1336	1297	1312	1334	1356
		σ	27.7	28.7	33.9	17.6	19.6	14.1	6.35	8.74
	Refuse	AVG	1151	1165	1177	1197	1160	1178	1197	1214
		σ	8.62	14.7	14.4	17.4	17.0	12.7	14.1	18.15
	Grate ash	AVG	1093	1106	1132	1167	1158	1173	1204	1293
		σ	9.81	11.9	5.51	32.5	23.5	21.0	11.5	16.5
	Coll. ash	AVG	1127	1138	1158	1175	1195	1210	1227	1251
		σ	19.05	19.1	35.2	35.9	26.1	30.9	39.0	41.2

(HT), and fluid temperature (FT). The determination of these values under either a reducing or an oxidizing furnace is specified in ASTM D-1857. No definitive correlations were made with regard to the listed ash softening temperatures though several distinctive features were noted.

The average ITs under an oxidizing atmosphere were 1240.3°C for all the 1976 coal and 1288.3°C for the 1978 coal. The average IT under an oxidizing atmosphere for the RDF was 1195.5°C, or 128.8°C lower.

Again, for ITs under an oxidizing atmosphere, the bottom ash and fly ash values were always lower than that for the coal. The decrease in IT for bottom ash was 67.5, 148.1, and 128.0°C for 0, 10, and 20% compared with the coal for the equivalent RDF firing rate. The decrease in IT for the fly ash was 23, 75, and 79.1°C compared with the coal for the equivalent RDF firing rate.

Thus, the lower ash fusion temperatures result in softer or more molten material on the furnace walls. It would seem that large pieces of RDF material would have a greater tendency to adhere to the walls and increase the slag buildup. When the upper furnace buildup became severe towards the end of July 1978, the walls were cleaned by the rapid dropping of load to 12 MW. This load drop imposed a thermal shock on the unit and resulted in shedding of material from the walls into the bottom hopper.

After completion of the process plant disc screen modification in December 1979, the wall slagging was noticeably reduced. This may be attributed to the removal of the glass-sand fines by the use of the two disc screens.

SECTION 15

BOILER THERMAL PERFORMANCE

This section evaluates unit No. 7 while burning Iowa-Western coal mixtures with and without RDF. This performance evaluation includes excess air variation, boiler efficiency (indirect or loss method), fuel utilization, and general boiler operating data. The major impact of the dump grate is reflected in the good fuel utilization (or low bottom ash combustible loss) and the higher flue gas loss primarily due to the higher flue gas temperatures leaving the air heater.

In the installation of the dump grate, cold combustion air enters the furnace with the RDF transport injection air and with the undergrate and overgrate air. The reduction of combustion air passing through the air heater results in a lower amount of heat energy being removed from the flue gas passing through the air heater. This effect is considered in the discussion of boiler efficiency.

EXCESS AIR

The percentage of excess air indicates the additional amount of air supplied above that is required to produce ideal or stoichiometric combustion. For evaluation of unit No. 7, excess air percentages were calculated from measurements made during the flue gas particulate sampling before the ESP and from the flue gas sampled from a single port located before the air heater.

The gas sampling port before the air heater is actually positioned in the convection bank or back pass and is halfway between the upper and lower boiler drum. The aspirated flue gas sampling forms part of the Bailey Meter Company catalytic O_2 measurement apparatus and is the means by which the excess air value leaving the boiler (as a control signal) is supplied to the boiler control panel (and operator). A calibration curve was used by Bailey Meter to express the O_2 as an equivalent percentage excess air. The conversion essentially uses a design coal analysis and the ASME test code short-form procedure to calculate the percentage excess air. The boiler manufacturer's recommendation is to fire with 20% excess air at the boiler outlet (air heater inlet). Some of this aspirated flue gas sample was analyzed using an Orsat gas analyzer.

The procedure for determination of excess air from Orsat measurements was to use the ultimate analysis of the fuel and then to perform a carbon-nitrogen balance and alternatively a carbon-oxygen balance. A material balance was calculated for each method to indicate possible discrepancies in the analyses. The excess air determinations from both these calculations were then mass-averaged to produce a composite excess air value which would satisfy the material balance. This latter value, by the conventional combustion calculation technique, was used to compute the corrected

Orsat values. It should be noted here that the ASME boiler test code long-form procedure uses a carbon-nitrogen balance and seems to result in higher excess air values than does the short-form calculation procedure for any set of Orsat values.

Combustion air to the furnace is supplied by secondary air from the air heater discharge, primary air which is transporting the coal from the pulverizer discharge, cold undergrate air from a separate fan, cold overgrate air entering at the end through open observation doors, and the two diagonally-opposed RDF transport lines which supply 1.67 m^3/sec of cold air through the airlock feeder at the Atlas bin. The undergrate air was approximately 1.70 m^3/sec, and the total overgrate air flow rate was approximately 0.94 m^3/sec. Both flow rates were determined from velocity surveys made during some of the 1978 tests. The average grate air temperature was 31°C.

Table 82 presents the measured Orsat data, the calculated excess air results, and the corrected Orsat value from measurements made before the air heater. Table 83 lists the same parameters for measurements made at the inlet of the ESP (or air heater discharge). The excess air data as measured by the continuous O_2 monitor before the air heater and used by the operator for boiler control are also shown in Table 83.

The calculated percentage excess air and the continuously monitored excess air at the air heater inlet are also shown in Figure 73.

TABLE 82. EXCESS AIR AND ORSAT ANALYSES BEFORE THE AIR HEATER

% Load/% RDF		Orsat analysis			Excess air		Corrected	Calculated Orsat analysis			Continuous monitor excess
		CO_2 %	O_2 %	N_2 %	C/N_2 Balance %	C/O_2 Balance %	AVG %	CO_2 %	O_2 %	N_2 %	Air %
1976											
60/0	AVG	-	-	-	-	-	-	-	-	-	25.84
	σ	-	-	-	-	-	-	-	-	-	2.35
80/0	AVG	13.35	4.45	82.20	44.52	30.16	44.48	13.20	6.58	79.98	20.87
	σ	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.83
100/0	AVG	13.40	4.80	81.80	34.97	30.59	38.83	13.15	5.81	80.69	21.16
	σ	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.87
1978											
80/0	AVG	13.10	4.38	82.52	41.38	29.00	41.88	12.91	6.33	80.51	21.55
	σ	0.64	0.07	0.71	6.17	0.54	4.45	0.63	0.48	0.11	0.40
80/10	AVG	13.17	4.19	82.64	39.73	27.16	40.11	12.99	6.18	80.60	22.83
	σ	0.40	0.18	0.41	3.91	1.55	3.43	0.44	0.39	0.10	1.49
80/20	AVG	13.17	4.67	82.17	40.79	30.54	41.70	13.02	6.36	80.43	22.57
	σ	0.47	0.09	0.57	5.28	0.30	4.27	0.55	0.46	0.03	1.62
100/0	AVG[a]	13.02	4.96	82.03	41.18	32.87	42.52	12.91	6.42	80.51	22.51
	σ	0.12	0.04	0.16	1.82	0.17	1.45	0.17	0.14	0.04	1.98
100/10	AVG	13.85	4.48	81.67	31.16	27.79	33.41	13.69	5.40	80.70	17.27
	σ	0.74	0.75	0.45	6.58	5.60	5.80	0.79	0.70	0.087	1.28
100/20	AVG	13.89	3.95	82.16	33.46	24.52	34.67	13.77	5.58	80.47	17.02
	σ	0.25	0.19	0.061	2.45	1.75	2.03	0.27	0.21	0.006	0.03
1977											
224		-	-	-	-	-	-	-	-	-	15.67
225		-	-	-	-	-	-	-	-	-	16.31

[a] EPA 314 Orsat erratic: results in negative air heater leakage.

TABLE 83. EXCESS AIR, ORSAT ANALYSIS AND AIR HEATER LEAKAGE, AIR HEATER OUTLET (BEFORE PARTICULATE COLLECTOR)

		Orsat analysis			Excess air		Corrected	Corrected Orsat analysis			Air heater leakage	
Load/RDF[a]		CO_2 %	O_2 %	N_2 %	C/N_2 balance %	C/O_2 balance %	AVG %	CO_2 %	O_2 %	N_2 %	Mass diff. %	CO_2 diff. %
1976												
60/0	AVG	11.86	6.81	21.33	65.76	51.95	62.2	11.91	8.18	79.80	-	-
	σ	0.58	0.97	0.82	3.98	8.42	4.17	0.57	0.35	0.39	-	-
80/0	AVG	12.27	6.11	81.62	56.90	44.07	53.26	12.34	7.42	80.23	8.99	8.73
	σ	0.78	1.10	0.75	8.13	9.20	7.53	0.77	0.73	0.31	0.0	0.0
100/0	AVG	11.6	6.67	81.73	64.13	50.00	60.04	11.68	8.05	80.27	11.57	11.52
	σ	0.59	0.42	0.37	9.03	5.69	8.25	0.60	0.66	0.21	0.0	0.0
1978												
80/0	AVG	11.32	6.92	81.76	66.95	53.07	63.47	11.36	8.30	80.34	12.96	12.75
	σ	0.28	0.25	0.21	3.80	3.12	3.77	0.28	0.29	0.12	5.22	5.30
80/10	AVG	12.06	6.46	81.47	55.60	46.33	53.30	12.09	7.44	80.46	8.69	8.55
	σ	0.83	0.74	0.10	9.59	8.10	9.22	0.83	0.84	0.07	7.05	7.06
80/20	AVG	11.52	7.67	80.82	63.33	57.83	61.87	11.54	8.22	80.25	12.99	12.88
	σ	0.12	0.73	0.61	0.56	5.78	1.02	0.13	0.09	0.06	2.43	2.63
100/0	AVG	11.79	6.31	81.90	60.08	46.22	56.50	11.84	7.74	80.43	11.43	11.29
	σ	0.41	0.47	0.20	6.92	5.30	6.61	0.42	0.57	0.15	0.73	0.74
100/10	AVG	12.39	5.66	81.95	51.88	39.23	48.63	12.44	7.04	80.52	10.51	10.59
	σ	0.36	0.59	0.26	2.61	4.91	2.86	0.34	0.28	0.09	2.44	2.57
100/20	AVG	13.02	5.45	81.52	46.65	36.77	44.04	13.07	6.56	80.37	6.24	6.23
	σ	0.86	1.05	0.22	9.55	9.92	9.36	0.84	0.90	0.06	4.80	4.81
1977												
100/10	AVG	11.70	7.05	81.26	59.09	47.90	56.58	11.61	8.23	80.07	-	-
	σ	0.99	0.88	0.11	12.11	9.24	11.55	1.15	1.11	0.11	-	-

[a] Percent.

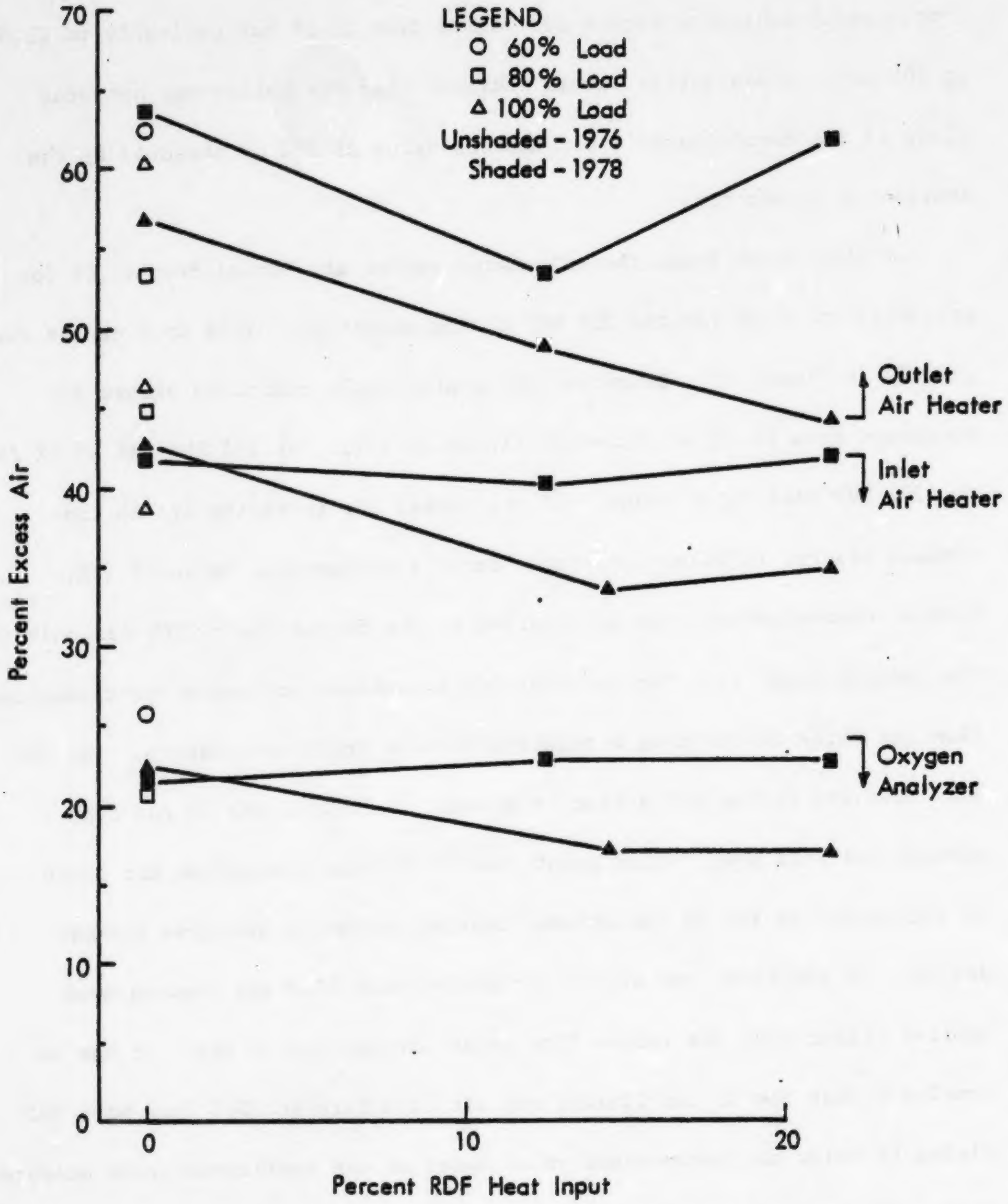

Figure 73. Percent excess air.

The calculated excess air at 80% steam load varied from 41.9% at coal-only firing to 41.7% at 20% RDF nominal heat input. At the same steam load, the continuously monitored excess air varied from 21.5% for coal-only to 22.5% at 20% RDF. These latter values indicate that the boiler was operated close to the manufacturer's recommended value of 20% as measured by the continuous O_2 monitor.

At 100% steam load, the calculated excess air varied from 42.5% for coal-only to 34.6% for the 20% RDF firing condition. This drop can be seen clearly in Figure 73. Likewise, the continuously monitored excess air decreased from 22.5% on coal-only firing to 17.3% for 10% RDF and 17.0% for the 20% RDF heat input tests. If the excess air indicated by the continuous monitor is below the manufacturer's recommended value of 20%, further combustion air can be supplied by the forced draft (FD) fan only if the induced draft (ID) fan can continue to exhaust or remove the combustion flue gas while maintaining a negative furnace draft or pressure. For the 100% load and firing RDF either at nominal 10 or 20%, the ID fan damper control was wide open, which meant that no further combustion air could be introduced by the FD fan without causing potential positive furnace drafts. In addition, the higher air heater exit flue gas temperatures implied higher flue gas volume flow rates through the ID fan. It can be concluded that the ID fan limited the air flow rate at 100% load with RDF firing to below the recommended value based on the continuous oxide measurement. However, examination of Figure 73 indicates that the excess air at the air heater inlet by Orsat measurements and calculations was well above the recommended 20% operating point. As discussed later, the resultant limit on air supplies influenced the wet flue gas flow out of the air heater and actually helped keep the boiler efficiency higher than that for the RDF firing tests at 80% load. The exit flue gas temperature variation with RDF firing is reviewed in the discussion of boiler efficiency.

The variation in the excess air at the air heater outlet is shown in Figure 73. At 100% steam load, excess air continuously decreased from 56.5% at coal-only to 44.0% at 20% RDF heat input. The impact of the ID fan limit on flue gas flow is seen on the excess air variation at the 100% load. At 80% steam load, the excess air was 53.1, 46.3, and 57.8% at the 0, 10, and 20% RDF firing rates, respectively.

AIR HEATER LEAKAGE

Air heater leakage (AHL) is defined as:

$$\text{AHL} = \frac{\text{mass wet flue gas out} - \text{mass wet flue gas in}}{\text{mass wet flue gas in}}$$

This parameter uses the material balance calculated from the corrected Orsat measurements. The AHL variation with percentage RDF heat input is listed in Table 83. At 80% steam load, the AHL was 12.8% at 0% RDF and 12.9% at 20% RDF. At 100% steam load, the AHL was 11.3% for coal-only firing and 6.2% at 20% RDF heat input. At 80% steam load, a large variation in Orsat readings occurred. The excess air was 53.1, 46.3, and 57.8% at the 0, 10, and 20% RDF firing rates, respectively.

BOILER EFFICIENCY

The boiler efficiency compares the heat added to the water with the heat input supplied by the fuel. The boiler efficiency was calculated by the use of the ASME indirect method, defined as:

$$\text{indirect} = [1 - \frac{Q_{loss}}{\text{fuel heat input}}] \times 100\%$$

where $Q_{loss} = Q_{loss}$ (dry flue gas) + Q_{loss} (combustible mash) + Q_{loss} (water in flue gas) + Q_{loss} (radiation)[a] + Q_{loss} (unaccountable warm-up).

The unaccountable heat loss factor is assumed to be 1-1/2% according to practice and as specified in the original manufacturer's performance contract (Appendix A). The heat loss due to water in the flue gas is calculated separately as the loss from the free moisture in the coal, the water formed from the hydrogen in the fuel, and the water in the combustion air.

The boiler efficiency and individual component heat losses are listed in Table 84. The variation in boiler efficiency with percentage RDF heat input is shown in Figure 74. The variation in the major component heat losses is depicted in Figure 75, which includes the dry gas, free moisture, hydrogen moisture, and unburned combustible, with percentage RDF heat input.

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[a] Estimated from ASME performance test code.

TABLE 84. BOILER EFFICIENCY (INDIRECT METHOD) AND COMPONENT LOSSES

Load/RDF %		Weight dry flue gas kg/kg fuel	Dry flue gas %	Heat loss, %			Unburned combustible %	Radiation %	Manuf. and unacc. %	Total losses %	Boiler efficiency %	Boiler a/ efficiency %
				Free moisture	Moisture in air	Moisture from H_2 in fuel						
1976												
60/0	AVG	10.67	6.65	2.32	0.04	3.17	0.50	0.50	1.50	14.67	85.33	85.08
	σ	0.71	0.48	0.65	0.02	0.52	0.02	0.0	0.0	1.07	1.07	1.16
80/0	AVG	10.47	6.25	2.04	0.03	3.55	0.55	0.43	1.50	14.35	85.61	85.26
	σ	0.90	0.82	0.43	0.02	0.62	0.16	0.0	0.0	1.32	1.32	0.95
100/0	AVG	11.81	6.12	1.37	0.02	3.32	0.76	0.30	1.50	13.38	86.62	86.03
	σ	0.97	0.37	0.30	0.01	0.52	0.31	0.0	0.0	0.65	0.65	0.44
1978												
80/0	AVG	12.05	7.18	1.81	0.29	4.09	0.23	0.41	1.50	15.60	84.40	84.14
	σ	0.67	0.29	0.12	0.07	0.14	0.05	0.0	0.0	0.16	0.16	0.29
80/10	AVG	10.25	7.59	2.33	0.24	4.68	0.45	0.41	1.50	17.21	82.79	82.60
	σ	0.68	0.74	0.16	0.02	0.10	0.09	0.00	0.0	1.00	1.00	0.99
80/20	AVG b/	9.86	8.33	2.69	0.24	4.97	0.59	0.41	1.50	18.90	81.10	80.83
	σ	0.07	0.03	0.08	0.01	0.01	0.05	0.0	0.0	0.01	0.01	0.13
100/0	AVG	11.30	7.23	1.80	0.30	4.13	0.39	0.30	1.50	15.65	84.35	84.19
	σ	0.77	0.33	0.15	0.04	0.15	0.09	0.0	0.0	0.25	0.25	0.27
100/10	AVG	10.08	7.03	2.24	0.26	4.49	0.38	0.30	1.50	16.20	83.80	83.56
	σ	0.41	0.16	0.11	0.02	0.32	0.04	0.0	0.0	0.40	0.40	0.35
100/20	AVG	8.35	6.68	2.81	0.27	4.89	0.53	0.30	1.50	16.98	83.02	82.81
	σ	0.43	0.40	0.02	0.03	0.03	0.12	0.0	0.0	0.28	0.28	0.26
1977												
	AVG c/	9.69	6.54	3.28	0.12	3.86	4.46	0.30	1.50	19.66	80.30	80.04
	σ	0.82	0.49	0.42	0.03	0.17	0.91	0.0	0.0	1.36	1.30	1.46

a/ Boiler efficiency corrected for design inlet temperature.

b/ EPA 301 values omitted-erroneous Orsat.

c/ Test runs--less than 2 hr.

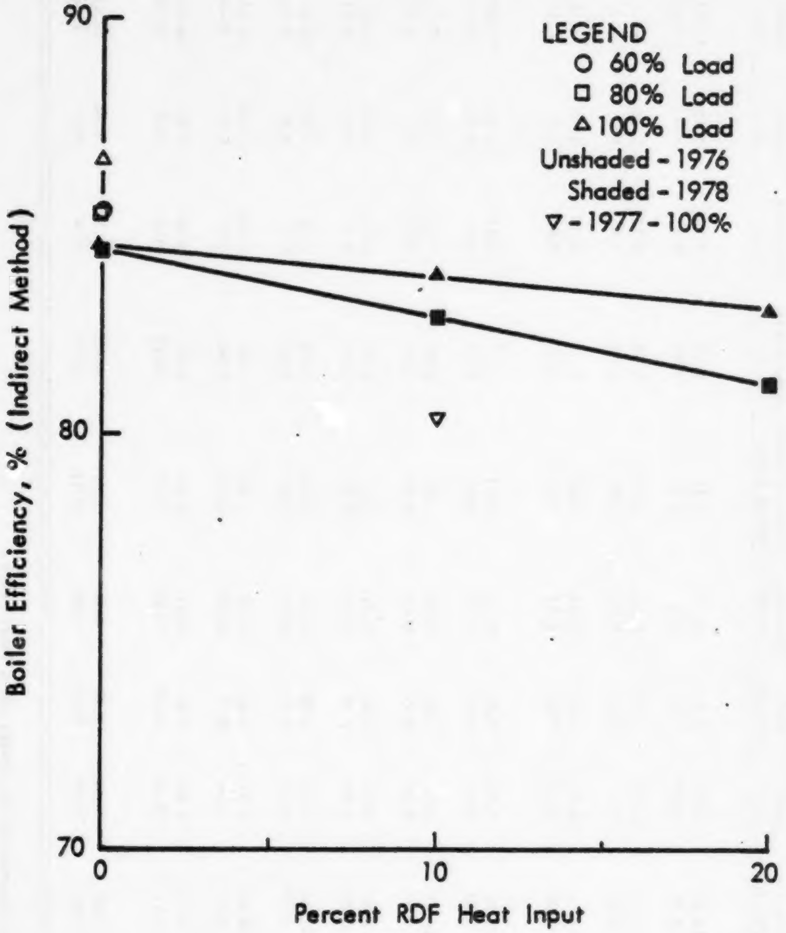

Figure 74. Boiler efficiency.

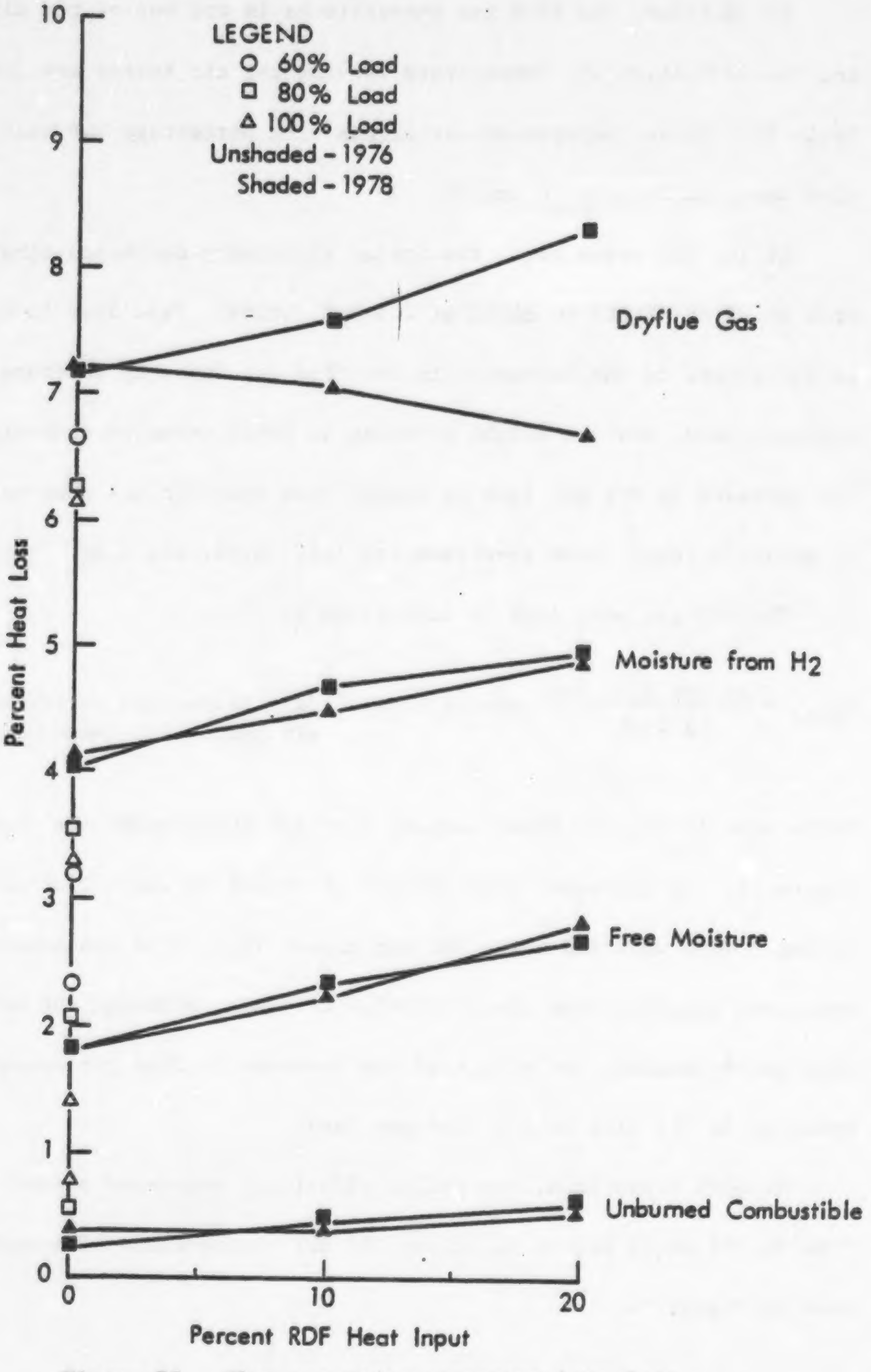

Figure 75. Flue gas major component heat loss.

In addition, the flue gas temperatures in and out of the air heater and the combustion air temperature leaving the air heater are listed in Table 85. These temperature variations with percentage RDF heat input are also shown in Figures 76 and 77.

At the 80% steam load, the boiler efficiency decreased almost linearly from 84.4% at 0% RDF to 81.1% at 20% RDF firing. This drop in efficiency is attributed to the increases in dry flue gas loss, H_2 moisture loss, free moisture loss, and the slight increase in total unburned combustible loss. The increase in dry gas loss is higher than that for the free moisture and H_2 moisture loss; these increases are 1.15, 0.88, and 0.88%, respectively.

The dry gas heat loss is calculated by:

$$Q_{\text{loss}} = \frac{\text{kg dry flue gas}}{\text{kg fuel}}\,(\text{specific heat})\,\left(\begin{array}{l}\text{air heater gas temperature out} - \\ \text{air heater air temperature in}\end{array}\right)$$

Variations in the air heater outlet flue gas temperature are shown in Figure 76. It increased from 186.1°C at 0% RDF to 216.4°C at 20% RDF firing. This occurred while the air heater inlet flue gas temperature decreased slightly from 356.1 to 349.4°C. Thus, although the weight of dry flue gas decreased, the effect of the increase in flue gas temperature resulted in the rise in dry flue gas loss.

At 100% steam load, the boiler efficiency decreased almost linearly from 84.35% at 0% RDF to 83.02% at 20% RDF firing rate. The variation is seen in Figure 74.

TABLE 85. COMBUSTION AIR AND FLUE GAS TEMPERATURES

		Air heater air temperature, °C		Air heater flue gas temperature, °C	
% Load/% RDF		In	Out	In	Out
1976					
60/0	AVG	44.6	313.0	331.3	179.5
	σ	3.6	2.5	3.1	2.4
80/0	AVG	50.3	328.0	353.0	182.1
	σ	16.9	4.3	6.0	14.0
100/0	AVG	60.0	343.0	383.2	184.4
	σ	9.3	1.2	5.8	7.3
1978					
80/0	AVG	45.9	336.0	356.1	186.1
	σ	2.6	3.5	2.2	4.4
80/10	AVG	42.2	337.0	351.5	200.0
	σ	1.1	1.2	3.1	4.7
80/20	AVG	46.9	341.0	349.4	216.4
	σ	1.2	0.0	0.0	2.0
100/0	AVG	42.0	354.0	385.5	191.7
	σ	1.6	0.6	2.0	2.4
100/10	AVG	44.1	350.0	373.1	196.3
	σ	5.0		3.8	4.7
100/20	AVG	43.2	353.0	377.4	198.9
	σ	1.3	1.0	0.6	2.8
1977					
100/10	AVG	45.5	N/A	372.8	176.7
	σ	4.7	N/A	0.0	0.0

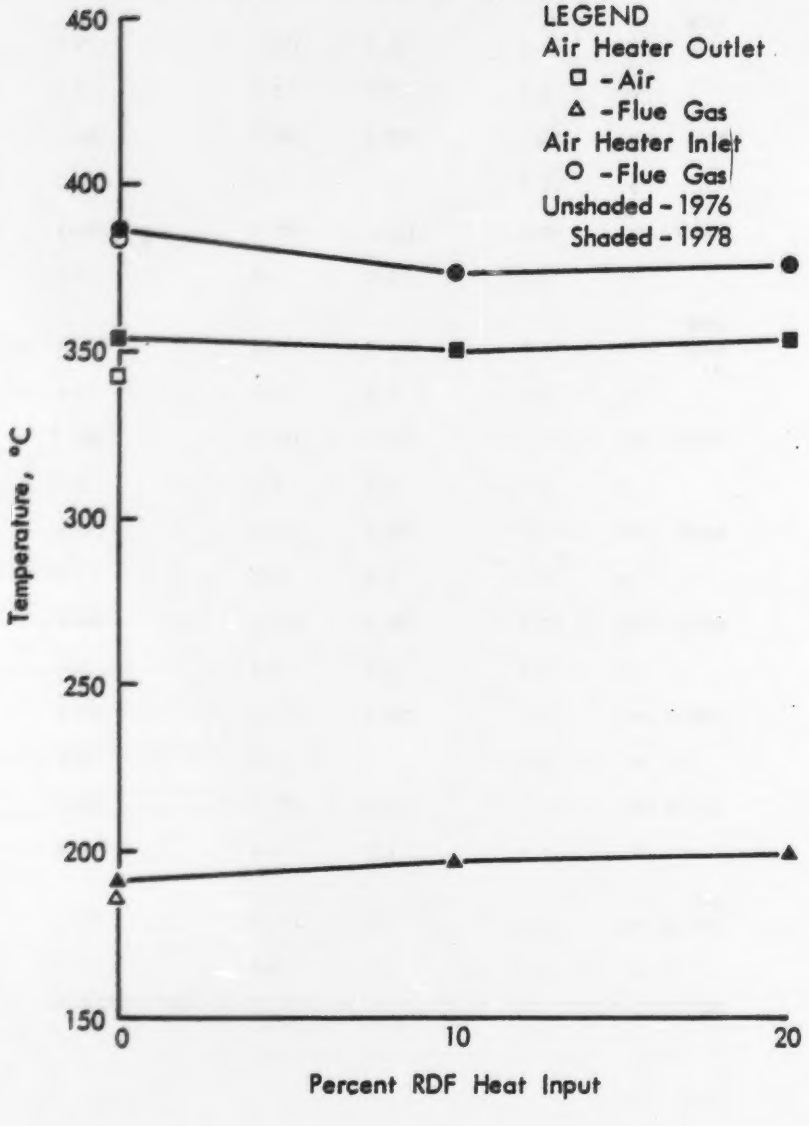

Figure 76. Air and flue gas temperature at 80% boiler load.

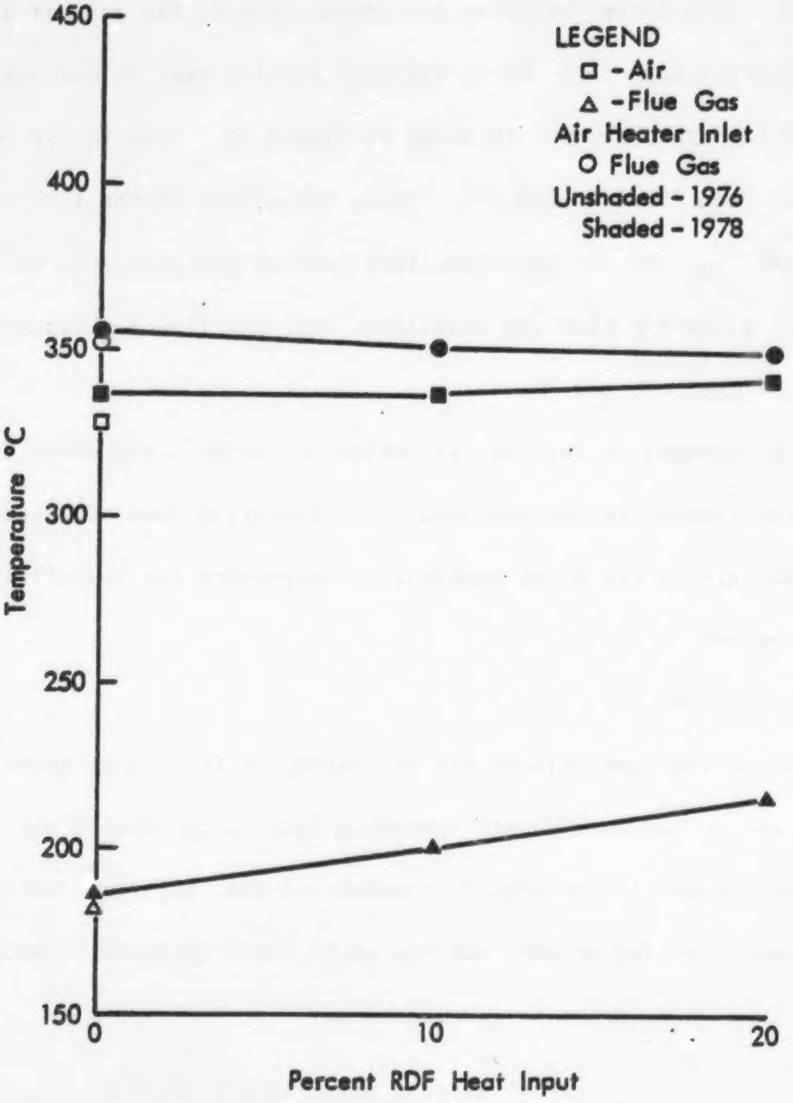

Figure 77. Air and flue gas temperatures at 100% boiler load.

Again, this decrease in efficiency is primarily due to the increases in the free moisture loss and the H_2 moisture loss, which were 1.01 and 0.76%, respectively. However, the dry flue gas loss decreased from 7.23 to 6.68 or 0.55%. This latter behavior attributed both to the greater drop in flue gas weight per unit fuel and to the much smaller rise in air heater outlet flue gas temperature which is shown in Figure 75. This latter temperature increased from 191.7 to 198.9°C. Thus, the effect of the limit on the ID fan volume flow and the resultant lower excess air proved to be beneficial in reducing the dry flue gas heat loss. Air and flue gas temperatures are shown in Figures 76 and 77.

In an attempt to improve the boiler efficiency, the power plant personnel are evaluating the possibility of rerouting some air heater outlet combustion air to the plant basement to supplement the underfire and overfire grate air.

FUEL UTILIZATION

Fuel utilization relates the percentage of total fuel heat input that is lost due to the combustible remaining both in the bottom ash and fly ash. The fly ash is the composite amount of that material removed by the ESP, known as collector ash, and the particulate emissions leaving the stack. Fuel utilization is calculated as:

$$\text{Loss} = \frac{\text{fuel heating value in ash (kJ/hr)}}{\text{fuel heat input (kJ/hr)}}$$

It is based on the measured bottom ash flow (using a sluice box at the ash pond) and the total measured fly ash emissions at the inlet of the ESP (also identified as "before particulate collector").

Tabulated values of bottom ash collector, ash stack emission, and total ash heat losses are given in Table 86. The fuel utilization or percentage heat loss for the bottom and total composite ash heat loss is shown in Figure 78.

The heat loss in the bottom ash for the 1978 tests at 100% load varied from 0.11% for coal-only to 0.20% while firing with nominal 20% RDF (heat input). At 80% steam load, the bottom ash heat loss was 0.04% for coal-only and 0.10% at 20% RDF heat input firing rates. Thus, installation of the bottom dump grates has provided for excellent burn-up of any material dropping to the furnace bottom during the burning of RDF. It should also be noted that the material on the dump grate is dumped every 60 to 70 min. The grate is left opened while firing only coal.

Total heat loss in all the ash for the 1978 tests at 100% load varied from 0.39% at coal-only to 0.53% at 20% RDF firing rates. This total loss is lower than the 2 to 6% losses experienced when the RDF is fired in the two stoker-fired units.

Measured bottom, ESP collector, and stack emission ash flow rates are also tabulated in Table 86. Bottom ash flow rates were determined by use of a sluice box, described earlier. The ESP collector flow rate was calculated from the difference between the fly ash flow rate measured at the ESP

TABLE 86. FUEL UTILIZATION

% Load/% RDF		Mineral ash input kg/hr	Ash flow rate				Percent of total ash out			Percent heat loss		
			Bottom kg/hr	Collector kg/hr	Emissions kg/hr	Total kg/hr	Bottom	Collector	Emissions	Bottom	Total fly Ash	Total
1976												
60/0	AVG	1,226.1	126.3	870.3	23.4	1,024.8	12.33	85.34	2.3	0.184	0.314	0.498
	σ	190.1	86.6	87.1	6.8	12.2	8.7	8.1	0.7	0.093	0.089	0.017
80/0	AVG	1,848.4	111.2	1,060.2	43.3	1,214.7	9.2	86.92	3.88	0.102	0.445	0.548
	σ	240.5	34.5	227.2	16.3	236.6	2.5	3.88	2.48	0.019	0.148	0.159
100/0	AVG	2,594.6	219.3	1,346.7	81.4	1,647.4	13.3	81.73	4.93	0.17	0.590	0.757
	σ	118.0	39.6	5.8	13.9	45.5	2.1	2.17	0.85	0.06	0.246	0.306
1978												
80/0	AVG	1,206.1	64.4	889.7	27.2	983.3	6.07	90.9	3.03	0.04	0.23	0.28
	σ	543.6	48.1	182.3	5.8	234.3	3.07	2.86	0.58	0.03	0.04	0.05
80/10	AVG	1,499.1	314.0	1,045.0	52.10	1,411.1	22.07	74.23	3.67	0.11	0.348	0.454
	σ	157.3	71.0	62.7	11.2	138.5	3.21	3.53	0.45	0.025	0.066	0.031
80/20	AVG	1,605.3	218.0	1,220.0	50.7	769.7	14.65	81.90	3.35	0.119	0.467	0.536
	σ	21.2	8.5	99.0	9.3	833.0	0.64	0.28	0.35	0.016	0.030	0.046
100/0	AVG	1,942.8	133.6	1,316.7	75.8	1,526.1	9.0	86.27	4.73	0.114	0.279	0.393
	σ	751.8	51.9	534.5	43.0	606.5	3.1	3.46	1.03	0.044	0.073	0.81
100/10	AVG	2,122.7	410.0	1,270.0	83.0	1,571.0	22.93	72.33	4.73	0.058	0.322	0.380
	σ	310.6	201.4	112.7	15.80	263.1	10.21	9.12	1.07	0.021	0.060	0.041
100/20	AVG	2,590.2	821.0	1,310.0	100.3	2,233.3	36.73	65.52	4.57	0.197	0.338	0.533
	σ	396.6	89.0	88.9	18.9	38.5	4.14	9.69	0.81	0.097	0.011	0.101
1977												
100/10	AVG[a]	2,209.1	1,245.0	1,460.0	110.9	2,815.9	44.05	51.95	4.00	3.775	0.472	4.247
	σ	24.4	247.5	56.6	32.7	271.4	4.45	2.90	1.56	1.356	0.151	1.508

a/ Test of short duration--sluicing difficulty.

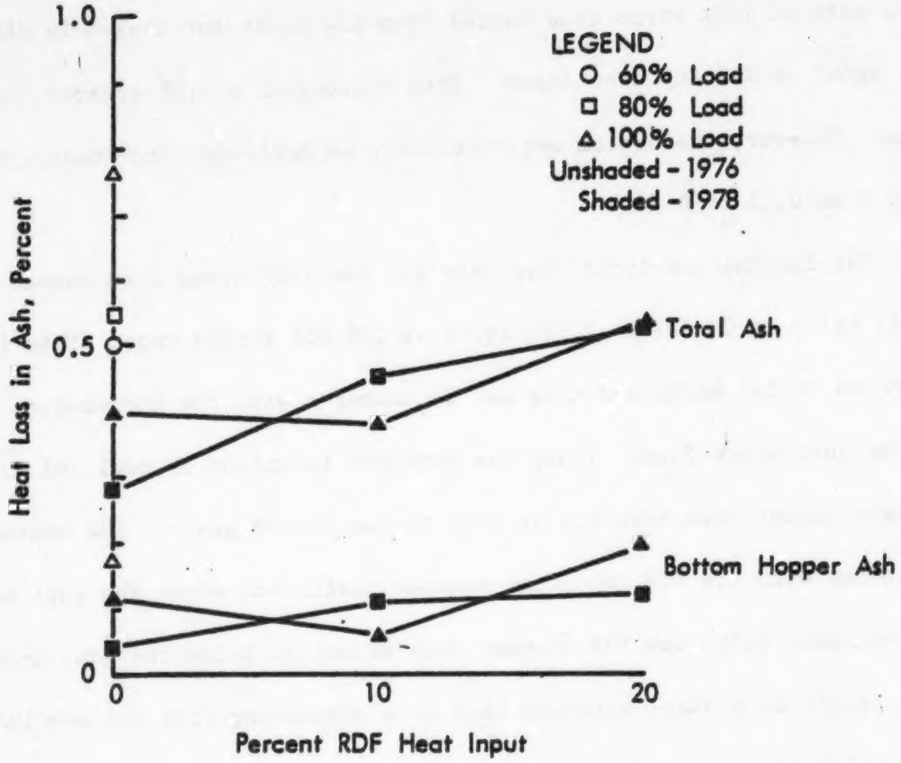

Figure 78. Heat loss in ash.

inlet and the particulate emissions measured at the stack sampling location. This gas sampling was accomplished using the filter catch EPA Method 5.

One main area of interest is the relative change in amount of bottom ash flow when burning coal plus RDF compared to coal-only. The bottom ash flow rate at 100% steam load varied from 134 kg/hr for coal-only firing to 821 kg/hr at 20% RDF heat input. This represents a 615% greater flow rate. However, the bottom ash heat loss, as mentioned previously, rose only from 0.11 to 0.20%.

The mineral ash input flow rate for the 100% steam load varied from 1,943 kg/hr at 0% RDF to 2,590 kg/hr at 20% RDF firing rate. This is an increase of 547 kg/hr and thus can be compared with the increase of 687 kg/hr in the bottom ash flow. Thus, the combined injection of coal and RDF has perhaps caused more downfall of coal to the bottom grate. The tests were performed with the RDF injection nozzles positioned above the coal nozzles. In September 1978, the RDF nozzles were relocated below the coal nozzles. The results of a stack emission test by a consulting firm did not include evaluating the impact on the bottom ash flow.

The bottom ash flow rate at 80% steam load varied from 64 kg/hr at coal-only firing to 218 kg/hr at 20% RDF input. At this steam load, the bottom ash flow rate was greatest at 10% RDF input with a rate of 314 kg/hr. Again, the bottom ash heat loss varied from 0.04% for coal-only to 0.10% at 20% RDF input. It should be noted that an attempt to perform a mass balance is extremely difficult. There will be an accumulation of slag on the furnace waterwall tubes and powdered ash on the convective pass tubes.

GENERAL OPERATING DATA

Average values for the boiler operating data are shown in Table 87 and include the coal and RDF firing rates and the heat input contribution from each of these fuels. The heating values associated with these fuels were given in Table 70. Because of the variation in the steam flows associated with the nominal 80 and 100% of the rated turbine capacity (35 MW), the heat input per kilogram of steam flow was calculated and is also shown. At the nominal 80% load, the heat input per unit flow of steam increased from 2,759.7 kJ/kg at the 0% RDF firing rate to 2,914.1 kJ/kg, reflecting the decrease in boiler efficiency discussed previously. At 100% nominal boiler load, the heat input per unit steam flow increased from 2,732.5 kJ/kg water to 2,876.2 kJ/kg H_2 at 20% RDF firing rate. Again, this increase in heat input is reflected by the decrease in boiler efficiency.

Initial testing of unit No. 7 in 1978 started at the 80% load condition with 20% RDF. As the summer progressed, increased slagging was experienced above the upper burner level, especially along the back furnace wall under the arch. Slagging of the furnace waterwall can result in reduced furnace heat transfer and higher furnace exit gas temperatures. This latter effect can cause higher superheat steam temperatures and the requirement for increased superheat spray at temperature flow. Examination of water spray flows shows nominal increases at the 100% steam loads which were tested during July.

TABLE 87. BOILER OPERATING DATA - AVERAGES

% Load/% RDF		Firing rate		Heat input, 10^6 kJ/hr			Heat input	H_2O temperature, °C		Steam		H_2O spray	
		Coal (kg/hr)	RDF (kg/hr)	Coal	RDF	Fuel	(kJ/kg H_2O)	F.W. to boiler	Superheated steam	pressure (kPa)	Steam flow[a] (kg/hr)	flow (kg/hr)	Actual
60/0	AVG	10,551.3	0.	229.078	0.	229.078	2,882.7	179.1	476.7	5,958.0	79,467.0	1,855.7	0.
	σ	717.4	0.	3.772	0.	3.772	13.3	2.2	2.8	0.0	1,342.0	634.8	
80/0	AVG	14,444.4	0.	320.107	0.	7.264	49.7	4.8	2.4	25.2	1,331.5	1,052.8	0.
	σ	569.9	0.	7.264	0.								
100/0	AVG	16,795.3	0.	401.623	0.	401.623	2,776.1	205.3	478.9	6,027.0	144,667.0	7,877.3	0.
	σ	591.7	0.	4.515	0.	4.515	63.5	1.6	2.0	20.5	2,159.0	34.6	
1978													
80/0	AVG	13,632.7	0.	321.779	0.	321.779	2,759.7	199.1	476.8	5,990.0	116,600.0	5,798.0	0.
	σ	574.4	0.	9.670	0.	9.670	31.0	2.0	2.5	39.3	4,095.0	1,545.7	
80/10	AVG	12,387.0	3,095.3	289.067	43.161	332.227	2,812.5	196.1	476.3	5,979.0	118,167.0	4,052.0	12.99
	σ	250.1	79.6	1.033	2.837	3.678	22.6	1.1	1.7	18.5	833.0	238.7	
80/20	AVG	11,002.0	5,435.5	260.053	69.278	329.331	2,914.1	194.4	476.7	6,007.0	113,000.0	2,813.0	21.04
	σ	108.2	169.0	3.127	4.528	1.401	6.7	0.8	2.3	58.7	707.0	917.8	
100/0	AVG	17,968.3	0.	421.695	0.	421.695	2,732.5	209.0	484.7	5,991.0	154,333.0	6,785.0	0.
	σ	779.1	0.	4.306	0.	4.306	23.6	0.6	3.1	34.0	2,854.0	627.0	
100/10	AVG	15,669.3	4,488.3	377.422	63.617	441.039	2,873.2	209.1	478.4	6,011.0	153,567.0	6,040.0	14.42
	σ	774.2	487.4	18.991	1.710	17.283	122.3	2.2	2.0	38.0	3,166.0	310.0	
100/20	AVG	15,031.7	7,811.3	351.389	95.647	447.034	2,876.2	209.6	482.6	5,986.0	155,600.0	6,474.0	21.4
	σ	278.0	705.9	8.034	3.898	11.821	160.8	1.4	4.3	63.0	5,139.0	513.0	
100/10	AVG	18,321.5	3,799.5	393.458	42.836	436.295	3,089.5	208.6	475.5	5,993.0	141,250.0	5,126.0	9.82
	σ	702.2	190.2	9.969	5.138	15.107	167.2	2.0	0.7	0.0	2,758.0	2,694.0	

a/ Boiler design flow - 163,296 kg/hr.

In an attempt to quantify the performance of unit No. 7 while burning coal plus RDF in terms of heat rate and amount of bottom hopper dropout, an abbreviated heat rate test was performed on February 3, 1977. When coal-only was fired at a turbine load of 32 MW, the gross heat rate was 12,231 kJ/kwh. When coal plus 15.9% RDF (by heat input) was fired, the gross heat rate was 13,303 kJ/kwh. The increase in bottom hopper ash flow rate was 899% or nine times greater than the equivalent bottom ash flow rate for coal-only firing at the same turbine load. For a RDF firing rate of 4,206 kg/hr, the equivalent amount of unusable RDF was 2,133.7 kg/hr. The increase in gross heat rate was 8.8%. The bottom hopper filled with dropout material in just over 1 hr. The RDF firing was stopped, and over 2 hr were needed to sluice the material out because of repeated pluggages of the clinker grinder and the sluice line. The material had to be manually pushed from one end of the bottom hopper towards the opposite outlet end.

In August 1977, two tests were again made to evaluate RDF firing prior to dump grate installation. These were made to evaluate stack emissions. At the 100% steam load and 10% RDF firing rate, the heat input per unit steam flow was 3,089.5 kJ/kg and represented an 11.3% increase in heat output over that for coal-only firing in 1976. Again, the hopper rapidly became filled with dropout material and sluicing was started 1-1/3 hr after commencement of RDF firing. RDF firing was stopped, and again 2 to 3 hr were required to empty the bottom hopper. In summary, the 1978 test results more than justify the installation of the bottom hopper dump grates.

The variation in excess air is under scrutiny by power plant personnel and modifications are tentatively planned to supply underfire and overfire grate air from the hot air heater discharge.

SECTION 16

CORROSION

At the time of this draft report preparation, the results of corrosion studies were not complete. They will be added at a later date.

SECTION 17

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APPENDIX

ORIGINAL BOILER DESIGN

TABLE A-1. BOILER DESIGN PERFORMANCE - UNIT NO. 7

Performance Data Design - Combustion Engineering Co. type VU-3 steam generator, Raymond RB 613 coal pulverizers, Ljungstrom air regenerative heater; fuel-Iowa Coal; Moisture, 17.12%; Volatile matter 32.27%; Fixed Carbon 37.10%; Ash 13.51%; Heating Value 21064.3 kJ/kg; ultimate analysis: C 51.1%; H 5.69%; N 1.00%, O 24.60%; S 4.10%; Ash 13.51%; Ash softening temperature 1054.4°C; Grindability 60

	60% rating	100% rating
General		
1. Kilograms of steam per hour actual evaporation	97,977.6	163,296.0
2. Steam pressure, superheater outlet, kPa	6,305.5	6,205.5
3. Steam temperature, superheater outlet, °C	485	485
4. Drum pressure, kPa	6,412.4	6,722.6
Temperature, °C		
5. Feedwater to boiler	190.6	220.0
6. Air to regenerative heater	45.6	36.1
7. Air out regenerative heater	324.4	343.9
8. Flue gas into regenerative air heater	362.8	401.7
9. Flue gas out regenerative air heater (corrected)	131.7	139.4
10. Coal-air to burners	76.7	76.7
Heat Balance, Percent, %		
11. Excess air at regenerative air heater inlet	22.0	22.0
12. Dry gas loss	3.90	4.67
13. Loss due to H_2O and H_2O in fuel	6.03	6.15
14. Loss due to moisture in air	0.09	0.11
15. Loss due to unburned combustibles	0.50	0.50
16. Loss due to radiation	0.37	0.31
17. Unaccounted losses	1.50	1.50
18. Total heat loss	12.89	13.24
19. Boiler efficiency	87.11	86.76

TABLE A-1. (continued)

	60% rating	100% rating
Flow Rates		
20. Flue gas leaving boiler, kg/hr	126,100.8	200,944.8
21. Flue gas leaving regenerative air heater including leakage, kg/hr	137,894.4	219,088.8
m^3/s	45.3	73.2
22. Air entering regenerative air heater		
kg/hr	117,482.4	191,872.8
m^3/s	31.0	49.1
23. Air leaving regenerative air heater, kg/hr	105,462.0	173,728.8
24. Priming air to pulverizers, total kg/hr	37,013.8	44,089.9
25. Tempering air to pulverizers kg/hr	12,519.4	9,298.8
26. Regenerative air heater leakage kg/hr	12,020.4	20,774.9
27. Fuel burned	13,018.3	20,774.9
Forced Draft Fan		
28. Air inlet temperature °C	26.7	26.7
29. Air flow, kg/hr	117,482.4	191,872.8
30. Air flow, m^3/min	1,744.5	2,832.0
31. Fan static, pressure, kPa	1.27	1.93
32. Static efficiency, %	31.6	54.6
33. Power required, kW	117.1	167.1
34. Fan speed, rpm	1,180	1,180
Induced Draft Fan (air foil)		
35. Flue gas inlet temperature °C	129.4	137.2
36. Flue gas flow, kg/hr	137,894.4	219,088.8
37. Flue gas flow, m^3/min	2,690.4	4,361.3
38. Fan static resistance, kPa	0.82	1.79
39. Static efficiency, %	24.7	52.3
40. Power to fan shaft, kW	149.2	249.9

TABLE A-2. PROPOSED BOILER UNIT NO. 7 PERFORMANCE - INITIAL MODIFICATION FOR RDF FIRING

		100% coal	90% coal[a] 10% RDF	85% coal[a] 15% RDF
Steam flow, kg/hr		163,296	163,296	163,296
Superheater outlet temperature	°C	485.0	485.0	485.0
Superheater outlet pressure	kPa	6,205.5	6,205.5	6,205.5
Heat input, fuel				
Total	10^6kJ/hr	457.9	466.3	469.5
coal	10^6kJ/hr	457.9	422.0	403.0
RDF	10^6kJ/hr	--	44.3	66.5
Flue gas leaving boiler	kg/hr	199,584	203,212.8	204,120
Total air required	kg/hr	181,440	183,254.4	183,708
RDF transport line air	kg/hr	--	7,801.9	7,801.9
Mill tempering air for coal	kg/hr	10,432.8	13,608.0	14,968.8
Air heater leakage	kg/hr	17,690.4	17,690.4	17,690.4
Air flow leaving FD fan	kg/hr	188,697.6	179,534.9	178,627.6
Excess air, boiler outlet	%	22.0	22.0	22.0
Air leaving air heater	kg/hr	171,007.2	161,481.6	160,574.4
Flue gas temperature into air heater	°C	388.9	388.9	388.9
Flue gas temperature out,	°C	139.4	144.4	146.1
Air temperature into air heater	°C	36.1	30.0	28.9
Air temperature out air heater	°C	335.6	342.2	343.9
Boiler efficiency	%	87.15	85.55	84.98

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[a] Two pneumatic transport lines in operation

TABLE A-3. UNIT NO. 7 EQUIPMENT DESIGN DETAILS

Total Effective Heating Surface		
Boiler	1537.5 m^2	
Furnace, EPRS*	576.0 m^2	
Superheater		
Convection	483.1 m^2	
Radiant	167.2 m^2	
Air heater	6242.9 m^2	
Furnace volume	772.6 m^3	
Furnace width and depth	6.07 m x 6.07 m	
Furnace design pressure	1.99 k Pa	
Tubes (O. D. x thickness)		
Waterwall	6.35 cm x 0.46 cm	
Boiler	6.35 cm x 0.30 cm	
Superheater	5.62 cm x 0.34, 0.51, 0.56 cm	
Bottom ash hopper		
Manufacturer	Allen Sherman-Hoff	
Size	5.92 m x 3.2 m	
Capacity, ash	15.85 m^3	
Type	Waterfilled	
Coal Pulverizers		
Number	2	
Type and size	Bowl Mill No. 613	
Manufacturer	C.E. Raymond	
Maximum capacity	14,515.0 kg/hr	
Minimum capacity	3,629 kg/hr	
Power	224.0 kW	
Feeders		
Manufacturer	Stock Equipment Company	
Type	Gravimetric	
Number	2	
Capacity each	13,605 kg/hr	
Fans		
Model No.	4054	4073
Manufacturer	Westinghouse	
Speed, rpm	1180	885
kw, test block	270.8	373
Flow rate	67.0 m^3/s	101 m^3/s
Static pressure	3.14 k Pa	3.19 k Pa

TABLE A-3. (continued)

Electrostatic Precipitator	
Manufacturer	American-Standard
Model No.	371
Efficiency	98.0%
Regenerative Air Heater	
Manufacturer	C.E. Air Preheater Company
Type and size	22-HR-64

Ash and Fly Ash Removal System

Boiler unit No. 7 is equipped with an Allen Sherman Hoff system for removal of ash, pyrite, and fly ash. The bottom ash is sluiced from the bottom hopper through a clinker grinder and is then hydraulically sluiced by a 4.17 m^3/min jet pump through a 549 m long gravity discharge line to the ash pond. Fly ash from the ESP hopper is first removed pneumatically by a hydraulically operated evacuator and then is mixed with the ejector operating water stream and is finally discharged through the 549 m long ash line to the pond.

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* EPRS = effective projected radiant surface.